Government of **Western Australia**
Department of **Mines, Industry Regulation and Safety**
**Dangerous Goods Safety**

Incident investigation report

# Ammonium nitrate emulsion tanker trailer explosion

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## Reference

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*Note: All figures are supplied by the Department of Mines, Industry Regulation and Safety, unless credited otherwise.*

# 1 Foreword

A tanker trailer and dolly transporting ammonium nitrate emulsion (ANE) were destroyed on the Great Central Road, Western Australia, on 24 October 2022. This was as a result of a tyre fire in the rear of two trailers, which led to a destructive explosion approximately two hours later. The explosion had significant force and destroyed the tanker trailer and dolly, propelling some large pieces of steel several hundred metres.

The Department of Mines, Industry Regulation and Safety (the Department) initiated an incident investigation as provided for by Part 6 of the *Dangerous Goods Safety Act 2004* (WA) [the DGS Act]. This report summarises the findings of the investigation conducted by Dangerous Goods Safety (DGS).

This report details the scientific investigation into the explosion including:

- a detailed summary of the course of events
- a description of the scene of the incident and observations
- an assessment of the effects of the blast damage and the location of key pieces of shrapnel from the explosion
- the identification of likely causes of the explosion and contributing factors
- recommendations for industry and regulators to mitigate the likelihood of another ANE transport explosion.

All references in this report to 'ANE' means an ammonium nitrate emulsion in its true, narrow sense and does not include an ammonium nitrate suspension (also referred to as a slurry) or a gel derived from a suspension. Suspensions and gels are different in physical and chemical properties to the product in question, notwithstanding that they are also non-explosive precursors for bulk explosives.

The Department's investigation team consisted of Dr Peter Drygala, Mr Henry Zuidersma and Ms Erin James, who are appointed as Dangerous Goods Officers under Section 27(1) of the DGS Act. This team was ably assisted by numerous other Dangerous Goods Officers.

The Department of Mines, Industry Regulation and Safety would like to acknowledge the Yilka Talintji people, past and present, who occupy the land where this incident occurred.

The Department acknowledges the valuable contributions provided to the investigation from Gruyere Gold Fields Joint Venture (JV), MACA Pty Ltd, Agspread, the tanker manufacturer, Enaex Australia, Department of Fire and Emergency Services (DFES), CSBP Limited, the Shire of Laverton and the Western Australian Police Force (WA Police).

**Iain Dainty**
Chief Dangerous Goods Officer

# 2 Executive summary

On 23 October 2022, a double road train, consisting of a prime mover carrying a tri-axle lead tanker, tri-axle dolly and a tri-axle rear tanker, was loaded with 61.61 T of ammonium nitrate emulsion (ANE) [UN 3375] at Kwinana, Western Australia. The vehicle was bound for the Gruyere mine site, which is approximately 1,175 km north-east of Perth.

The driver slept overnight near Leonora, 800 km north-east of Perth, before continuing to the mine, which is located 200 km north-east of Laverton. Leaving Leonora, he travelled via the Great Central Road that runs 1,126 km from Laverton, Western Australia to Yulara, Northern Territory. The road is sealed bitumen for the first 50 km out of Laverton, with the remaining 150 km to the mine site composed of unsealed gravel.

After travelling 96 km on the unsealed road, the driver saw black smoke amongst the dust generated behind the vehicle. Immediately, at 9:31 am, he pulled over a little to the side of the road and found the two rear tyres of the rear tri-axle group on the passenger (left-hand) side on fire. Over a period of approximately 14 minutes he attempted to extinguish the fire, which was increasing in intensity. He used all three onboard fire extinguishers but was unsuccessful in extinguishing the fire.

The driver then disconnected the rear tanker and dolly from the rest of the road train and drove 3 km further east to the turn-off to the mine. The driver used the vehicle to barricade the road, stopping other vehicles from entering the area from the eastern approaches and waited for assistance. The emergency response team from the mine site arrived approximately an hour later and entered the barricaded area at 11:05 am, to provide assistance to two vehicles passing the alight tanker and dolly. They witnessed the front of the dolly was alight and burning from the ground. They also observed white smoke, characteristic of decomposing ammonium nitrate (AN), as a result of a loss of containment from the tanker.

Two hours and two minutes after the driver first noticed the fire, at 11:33 am on 24 October 2022, the tanker exploded. This is the world's first detonation involving ANE during transport since bulk transport of ANEs was introduced in the 1980s. Because of the significance of this event, the Department of Mines, Industry Regulation and Safety (the Department) promptly organised an investigation team to travel to the remote site to undertake an investigation.

The explosion completely destroyed the dolly and tanker trailer and formed a large, shallow crater in the road, with the deepest point being approximately 1.1 m deep. The crater was irregular in shape, very roughly elliptical, 17 m long by 9 m wide, with a total area of approximately 120 m$^2$.

The blast threw thousands of pieces of aluminium and steel shrapnel, the majority to the south-east of the road (which ran from west to east). It included in excess of 50 kg of solidified molten aluminium that was on the ground at the time of the explosion. The solidified molten aluminium pieces provide evidence of the vehicle tank melting and a loss of containment of ANE before the explosion. This finding is consistent with the trajectory of the steel shrapnel, indicating an explosion from the ground upwards rather than an explosion from inside the ANE tanker.

The largest pieces of steel shrapnel found were a piece of a dolly axle suspension arm in excess of 100 kg at 413 m from the blast site, a 60 kg brake drum at 97 m and a 31 kg piece from the dolly turntable at 672 m, all located in a south-easterly direction from the crater. The 31 kg piece from the dolly turntable was almost fully embedded within the soil when located, consistent with a ground-based explosion.

The blast wave damaged the surrounding bush. Two concentric circles of varying degrees of blast damage were observed. An inner circle of trees and shrubs up to a distance of 40-50 m were completely flattened and some trees up to 7 m high were uprooted by the blast wave.

A wider circle extended up to 120 m from the crater consisting of snapped branches, 75-110 mm thick. Beyond 120 m, the overpressure was too weak and branches remained intact. From this damage it was estimated that the blast overpressure at 120 m may have been of the order of 14 kPa, which gives a rough estimate of the size of the explosion of approximately 1-3 tonnes of TNT equivalent. This is a small fraction of the potential explosive power of the 33.85 tonnes of ANE initially present in the tanker trailer.

The detonation sent up a plume of smoke approximately 1 km into the sky and the hot metal shrapnel that was thrown started numerous small spot fires in the surrounding bush. These self-extinguished, leaving patches of white ash behind.

The likely cause of the tyre fire was a loss of pressure in the air supply line that operates the tanker trailer's braking system. This caused the brakes to be applied and overheat, leading to a fire on the rear tri-axle passenger-side tyres on the rear trailer.

This report details the observations and findings around the crater site and explains what circumstances aligned to enable the explosion. It provides recommendations on how to improve the safety of transporting ANE. It was a preventable incident, because it was caused by a tyre fire and a range of practical improvements can be made to vehicle and transport operations to better prevent and respond to tyre fires. Had the driver been able to extinguish the fire it would not have progressed to an explosion.

It was fortunate that the explosion occurred in a remote location and no one was injured. There was no property damage except for the loss of the rear tanker, dolly, the ANE and the crater damage to the gravel road.

The potential for ANE to explode after a loss of containment from an aluminium tanker is a new credible scenario. The circumstances that led to the explosion were those that promoted a prolonged and intense vehicle fire with the involvement of a high fuel load of all 26 tyres on the tanker trailer and dolly and the fuel component from the ANE itself. Other essential circumstances included the entrapment of the ANE around the burning tyres caused by the topography of the dirt road, and the warm, low-humidity and relatively still weather conditions.

The prolonged heating of ground-based ANE is thought to have resulted in the following decomposition sequence, as the burning ANE converts to molten sensitised AN, well-known to be explosion sensitive. This will occur at different rates, depending on the distance to the burning tyres.

The sequence of events is:

- the destruction of the emulsion
- the boiling off of the protective water content
- combustion of the organic carbon content
- the formation of hot molten decomposing AN.

This was not an explosion of ANE, but an explosion of the resulting decomposing AN.

This particular explosion was unlikely to have occurred without the spread of the fire from the rear tri-axle group of 12 tanker tyres, past the 2 spare tyres on the tanker to the front tri-axle group of 12 dolly tyres.

The report makes recommendations on:

- practical measures that mitigate the likelihood of tyre fires
- practical improvements to the design of tanker trailers to protect them from the effects of fire.

It is desirable for industry to support and implement the recommendations, to improve both the safe transportation of ANE on Australian roads, as well as 'AN explosion risk goods', including solid AN prill and hot concentrated AN solutions (ANSOLs).

## 2.1 Recommendations

Recommendation 1 (page 84)
A national code of practice be developed by industry to provide detailed guidance on the safe road transport of 'AN explosion risk goods'.

Recommendation 2 (page 85)
Vehicles transporting 'AN explosion risk goods' should be fitted with a hub and tyre temperature and pressure monitoring system.

Recommendation 3 (page 86)
Mudguards with heat shielding properties (e.g. stainless steel) should be fitted, to protect the tank or cargo containing 'AN explosion risk goods' from the heat radiation of a tyre fire.

Recommendation 4 (page 86)
Consideration should be given to the practicality of fitting fire screens beneath loads of 'AN explosion risk goods'.

Recommendation 5 (page 87)
Critical components of the vehicle's running equipment should be protected from rocks and debris for the safe operation of the vehicle.

Recommendation 6 (page 88)

Vehicles should be fitted with a sufficiently large pressurised foam or water-based firefighting system that meets the requirements of Table 12.1 Note 4 of the ADG Code.

Recommendation 7

Automatic fire suppression systems should be considered for tyres of vehicles transporting 'AN explosion risk goods'.

Recommendation 8

In order to support recommendation 6, it is recommended that the National Transport Commission (NTC) should conduct a review of Table 12.1 Note 4 of the ADG Code.

Recommendation 9 (page 89)

The driver should be provided with a Journey Management Plan formulated after a risk assessment. Where possible, the transport of 'AN explosion risk goods' should avoid the use of poorly maintained gravel roads.

Recommendation 10 (page 89)

The maintenance schedule on vehicles should be intensified when driven on poorly maintained gravel or dirt roads.

Recommendation 11 (page 90)

Vehicles should carry an appropriate means of communication to be capable of raising the alarm at any point in the journey and to provide essential information to emergency services.

Recommendation 12 (page 91)

Emergency evacuation distances in the *Australian & New Zealand Emergency Response Guide Book*, Guide No. 140 should be increased to 1.6 km for fires involving ANE and ANSOL.

Recommendation 13 (page 91)
Drivers must be appropriately trained and competent in the safe and secure transport of 'AN explosion risk goods'.

Recommendation 14

Any party involved in a firefighting capacity of 'AN explosion risk goods' should be aware of when it is safe to fight a vehicle fire transporting these products and when evacuation processes should be undertaken.

Recommendation 15 (page 92)
Fire tests to be conducted to determine the rate of decomposition and explosive potential of ANE in open fires where the fuel and ANE entrapment are similar to the Great Central Road incident.

Recommendation 16

Fire tests to be conducted on steel tankers to determine the effectiveness of the new emergency venting requirements of AS 2809 part 4 (2022).

# 3 Background information on the use of ammonium nitrate emulsions in Western Australia

## 3.1 Introduction

Western Australia is the largest state in Australia by area and mining is its most important industry, vital to the economic wealth of the state and the nation.

Its mineral sector delivered sales valued at a record A$179 billion in 2021-22 (*Western Australian Mineral and Petroleum Statistics Digest 2021-22*). This result was driven largely by the iron ore industry with sales of A$137 billion from a record production of 844 million tonnes.

The second most valuable mineral is gold valued at A$17 billion received for 214 tonnes of gold.

WA remains Australia's highest gold producing state, representing 69% of the nation's production.

The WA mining industry uses more than 1.2 million tonnes of ammonium nitrate (AN) annually to make explosives to support the state's mining industry. Most of the state's AN is manufactured by two manufacturers, one in Kwinana and the other in the Pilbara. AN is also imported from overseas and interstate.

More than 99% of WA's mining explosives are based on AN and contain approximately 94% by dry weight of AN. The remainder is a fuel, most commonly a mineral oil such as diesel. Most of the AN is used to make ammonium nitrate emulsions (ANEs) and ammonium nitrate fuel oil mixtures (ANFOs). A small percentage of AN is used for AN gels or slurry explosives and packaged explosives used as primers for bulk explosives.

The ANEs consist of tiny sub-microscopic aqueous droplets of super-saturated AN solution (the dispersed phase) surrounded by a thin oily matrix (the continuous phase). The oily matrix is made up of a mineral or vegetable oil and a proprietary emulsifier and represents less than 10% of the volume of the emulsion. The emulsion is designed for the most intimate surface contact between oxidising agent and fuel, superior to any other two-component explosive.

ANEs are non-explosive precursor substances which are manufactured in large manufacturing plants by mixing a hot concentrated AN solution with the oily matrix in specialised equipment. WA has a number of ANE manufacturing plants across the state at critical locations to support the mining industry, including a number at state-managed explosives reserves.

ANEs are routinely delivered to mine sites across WA, mainly in aluminium or steel tankers. These tankers must traverse long distances, in regional and remote areas, often on unsealed and/or corrugated roads.

At the mine site the ANEs are transferred into large storage vessels and then into mobile processing units (MPUs), which transport the ANE to the blast hole. At the blast hole the MPU mixes a very small volume of sodium nitrite solution into the ANE and the reacting mixture is then pumped into the blast hole. The chemical sensitisation reaction involves the production of small nitrogen bubbles and occurs in the blast hole. This gassing effect changes the precursor into an explosive that is sufficiently sensitive to be initiated with the aid of a primer explosive.

ANEs have largely replaced the older AN water gels or slurry explosives technology. The reason for their large and growing market share is due to a combination of superior safety during transport, handling and use, high water resistance, ability to be safely pumped mechanically and the ability to be designed for a range of velocities of detonation. They can be tailor-made for use in any hardness of rock. This gives them a productivity advantage in most blasting applications over other bulk explosives.

Appendices 1 and 4 provide more detailed information about ANE and its properties.

## 3.2 United Nations classification

The international UN classification system for dangerous goods classifies ANEs as Division 5.1 dangerous goods oxidising substance if they pass a suite of tests (UN Test Series 8) detailed within the United Nations *Manual of Tests and Criteria, Seventh revised edition* 2019 (the UN Manual of Tests and Criteria). As ANE is transported by road it needs to pass tests a, b, c and d of the UN Test Series 8.

Once they pass all required tests, the UN classification system classifies the ANEs as Division 5.1 dangerous goods and excludes them from Class 1. Each ANE requires authorisation from the Chief Dangerous Goods Officer and the UN testing results are scrutinised by the Dangerous Goods Inspectorate as part of this process. ANEs are insensitive to friction, mechanical impact and spark.

## 3.3 Ammonium nitrate emulsion transportation

ANEs are transported at ambient (or close to ambient) temperature to mine sites in bulk, commonly in large road tankers that are mostly double and triple road trains. The tankers are specifically designed for transport of ANEs, made of aluminium or steel that comply with Australian Standard AS 2809 part 1 *General requirements for all road tank vehicles* and part 4 *Road tank vehicles for toxic, corrosive or ammonium nitrate emulsion, suspension or gel cargoes.*

The WA Dangerous Goods Safety (Road and Rail Transport of Non-explosives) Regulations 2007 (DG Transport Regulations) set out the obligations of persons involved in the transport of dangerous goods by road or rail to reduce as far as reasonably practicable the risks to people, property and the environment arising from the transport of dangerous goods. The regulations provide for the licensing of vehicles and drivers, the design approval of road tankers and mandates the emergency procedures in case of an incident, among other things.

For operations on WA roads, ANE tankers require licensing and approval under the DG Transport Regulations. To assist in the discharging of the viscous ANEs the tankers are shaped like a banana, see Figures 6.1 and 6.2.

Transport at sea requires ANEs to be transported in approved portable tanks or isotainers, which are steel tanks supported by a steel frame for multimodal lifting while fully loaded. Road transport of these isotainers is less frequent in WA and occurs mainly to and from the ports.

The transport of dangerous goods is closely regulated and enforced by the Dangerous Goods Inspectorate aided by the DG Transport Regulations. These regulations mandate the *Australian Code for the Transport of Dangerous Goods by Road & Rail Edition 7.8* (known as the Australian Dangerous Goods [ADG] Code) and provide nationally consistent requirements.

## 3.4 Safety and security of ammonium nitrate emulsions transported by road

The detailed safety requirements to transport ANEs by road are set out in the nationally adopted ADG Code and the state specific DG Transport Regulations.

The ADG Code requirements includes among other things:

- road tankers to be correctly placarded with the emergency information panels for ANE
- road tankers to be fitted with the correct fire extinguishers and personal protective equipment (PPE) for the driver
- accurate and accessible dangerous goods transport documents
- the correct Emergency Procedure Guide for a vehicle fire involving ANE or the *Australian & New Zealand Emergency Response Guide Book 2021*.

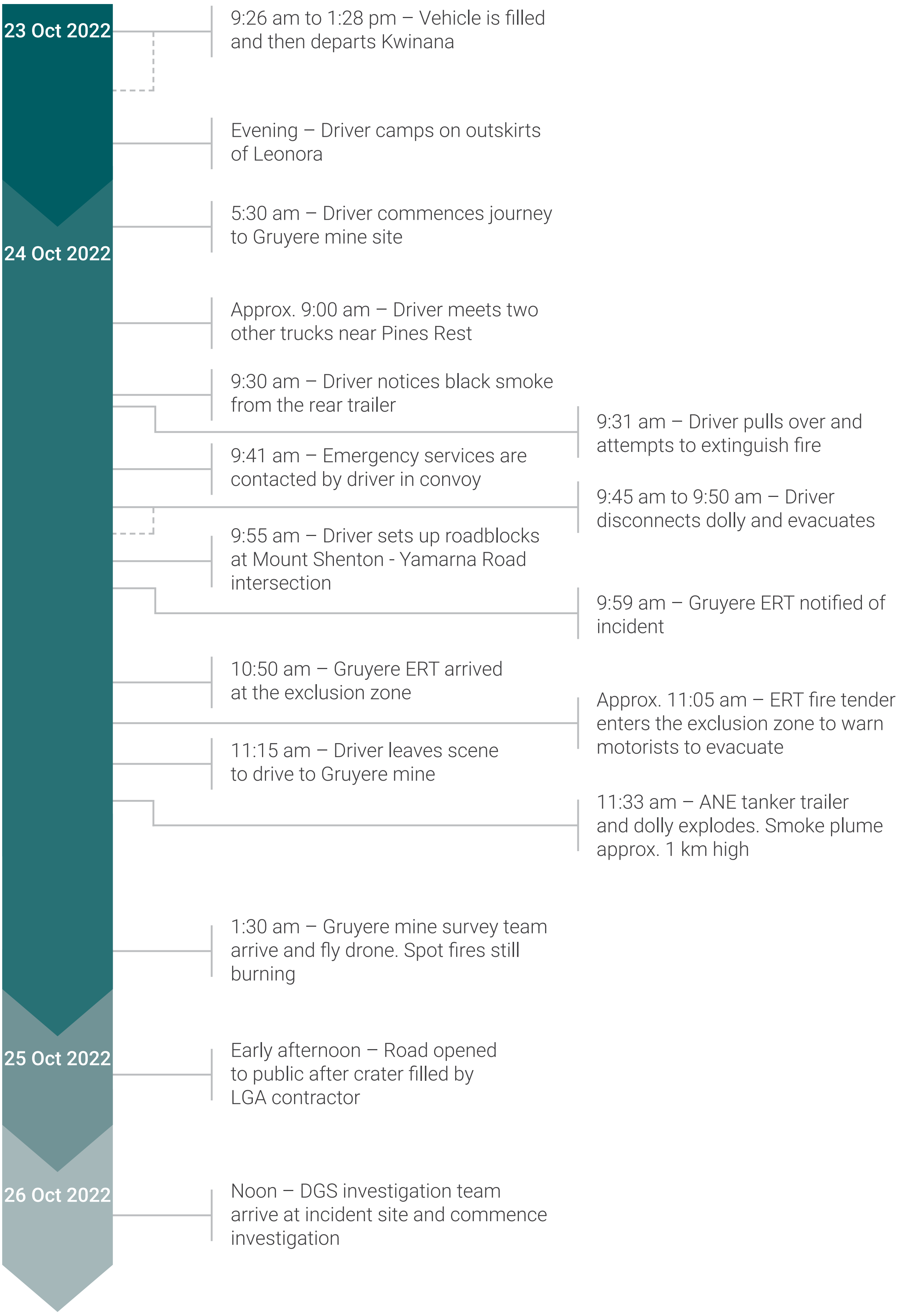
ANEs are nationally classified as belonging to a group of substances called 'security sensitive ammonium nitrate' (SSAN) as defined by the nationally consistent WA Dangerous Goods Safety (Security Sensitive Ammonium Nitrate) Regulations 2007 (SSAN Regulations). These regulations were introduced nationally as an anti-terrorist response and require the transport company to keep a security plan for transport and a SSAN transport licence. The licence holder must not allow anyone to have unsupervised access to the ANE unless that person has a security clearance from the Chief Dangerous Goods Officer and is authorised in writing by the licence holder to have unsupervised access to the SSAN. That person is called a secure nominee, for instance the driver must be a secure nominee of the licence holder.

The security plan contains many requirements and includes a risk assessment for sabotage and theft and details of the required measures that need to be put in place to prevent any unauthorised person to access the ANE during transport.

# 4 Accident description and timeline

This chapter provides an overview of the events that occurred leading to the explosion and the actions that different parties undertook. For detail on the likely causes of the fire refer to Chapter 8 and for the circumstances that increased the explosion risk refer to Chapter 9.

An abridged summary of significant events has been detailed in Figure 4.1. For a more detailed summary of events refer to Appendix 5.



**23 Oct 2022**

9:26 am to 1:28 pm – Vehicle is filled and then departs Kwinana

Evening – Driver camps on outskirts of Leonora

**24 Oct 2022**

5:30 am – Driver commences journey to Gruyere mine site

Approx. 9:00 am – Driver meets two other trucks near Pines Rest

9:30 am – Driver notices black smoke from the rear trailer

9:31 am – Driver pulls over and attempts to extinguish fire

9:41 am – Emergency services are contacted by driver in convoy

9:45 am to 9:50 am – Driver disconnects dolly and evacuates

9:55 am – Driver sets up roadblocks at Mount Shenton - Yamarna Road intersection

9:59 am – Gruyere ERT notified of incident

10:50 am – Gruyere ERT arrived at the exclusion zone

Approx. 11:05 am – ERT fire tender enters the exclusion zone to warn motorists to evacuate

11:15 am – Driver leaves scene to drive to Gruyere mine

11:33 am – ANE tanker trailer and dolly explodes. Smoke plume approx. 1 km high

1:30 am – Gruyere mine survey team arrive and fly drone. Spot fires still burning

**25 Oct 2022**

Early afternoon – Road opened to public after crater filled by LGA contractor

**26 Oct 2022**

Noon – DGS investigation team arrive at incident site and commence investigation

*Figure 4.1 Abridged summary of events*

*Note: all times are represented in Australian Western Standard Time (AWST) (UTC + 8) and some are approximated*

## 4.1 The journey

On 23 October 2022 a double road train, measuring 27.5 m in length, was loaded at CSBP Limited, Kwinana, Western Australia, with 61.61 tonnes of ANE (classified UN 3375). The product was to be transported to the Gruyere mine site, approximately 1,175 km north-east of Perth. The road train was a standard configuration – prime mover, front trailer, dolly and rear trailer – with the ANE contained within an aluminium "banana" tank on each trailer (Figure 6.1).

The driver left CSBP Kwinana at 1:28 pm for the Gruyere gold mine site. The driver drove on sealed roads to his overnight rest stop on the outskirts of Leonora, approximately 800 km from Perth.

The following morning he continued his journey to Laverton (125 km east of Leonora) on sealed roads, before continuing to the mine, which is located 200 km north-east of Laverton (Figure 4.2). Leaving Laverton, he travelled via the Great Central Road that runs 1,126 km from Laverton, Western Australia to Yulara, Northern Territory. The first 50 km of the road is sealed and then the road surface becomes unsealed (a gravel rather than bituminised road surface). The condition of the road deteriorates further to the east, with some ruts and corrugations, particularly after rain. Permanent speed limit signs are not used for unsealed gravel roads, as the condition of the road cannot be assured and vehicles must always be driven to suit road conditions.

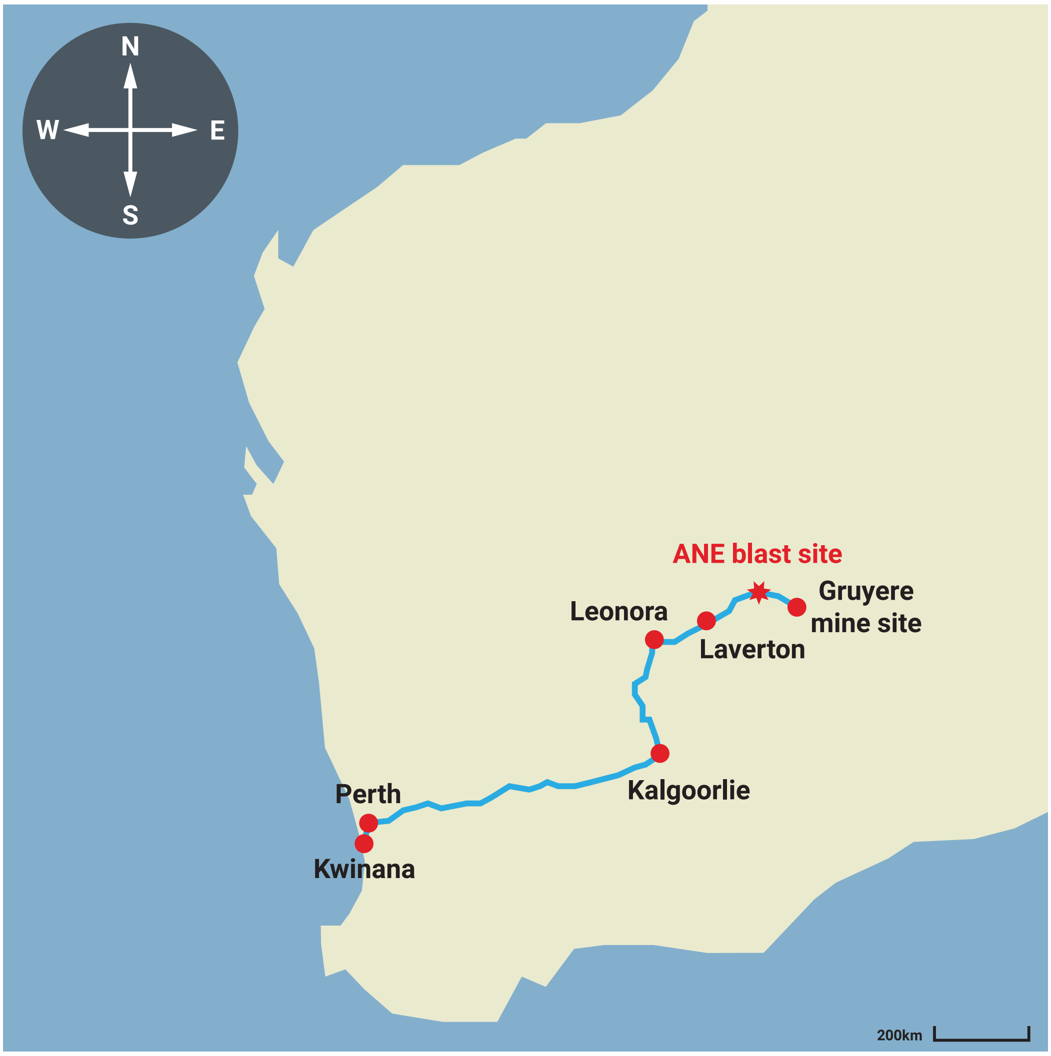


*Figure 4.2 The route of the vehicle and location of the incident near Gruyere mine site*

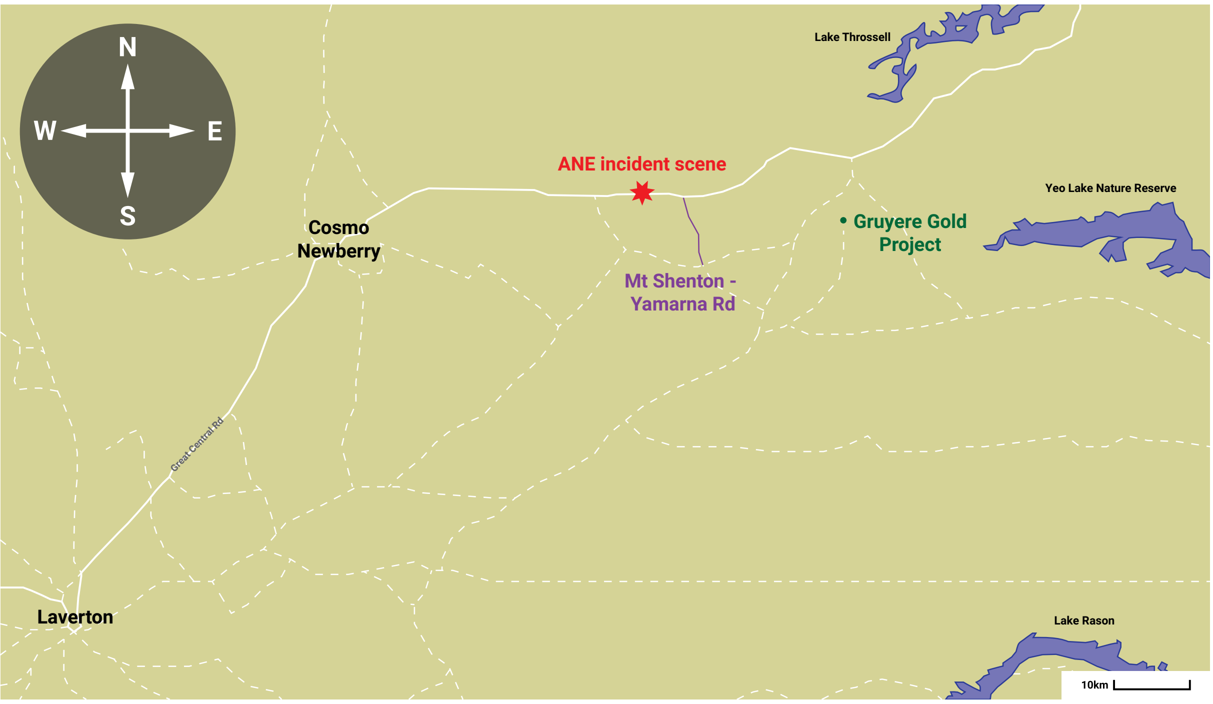


*Figure 4.3 Location of incident scene on Great Central Road*

After driving past the small community of Cosmo Newberry, the driver joined two other vehicles on the Great Central Road approximately 30 km before the incident scene (Figure 4.3). The driver then drove in convoy with them, as the last vehicle. As the driver did not stop at the community, there is no information about the condition of the vehicle at this point that might provide insight as to the cause of the subsequent tyre fire.

This part of the road was poorly maintained and the corrugations in the road forced the driver to travel at speeds of 30-40 km/h. It should be noted that the GPS tracking system was not operating in the time leading up to the incident, as it was out of mobile communication range. No physical records were collected to validate the speed that the driver was travelling. The estimates in speed travelled are from the driver's witness statement.

As a result of the road conditions a significant amount of dust was generated by the road train, which decreased the visibility and obscured the driver's rear vision and possibly prolonged detection of the fire.

At 9:31 am, after travelling 96 km on the unsealed gravel road and heading eastwards, the driver noticed black smoke among the dust in his rear mirrors on the passenger-side of the rear tanker trailer. The air pressure indicator light on the truck's dashboard was not noticed to be illuminated. If it was, it could have indicated a loss of air pressure from the reservoir tank (which is connected to the braking system).

The driver pulled over a little to the side of the road, approximately 3 m from the gully, to investigate (Figure 4.4).

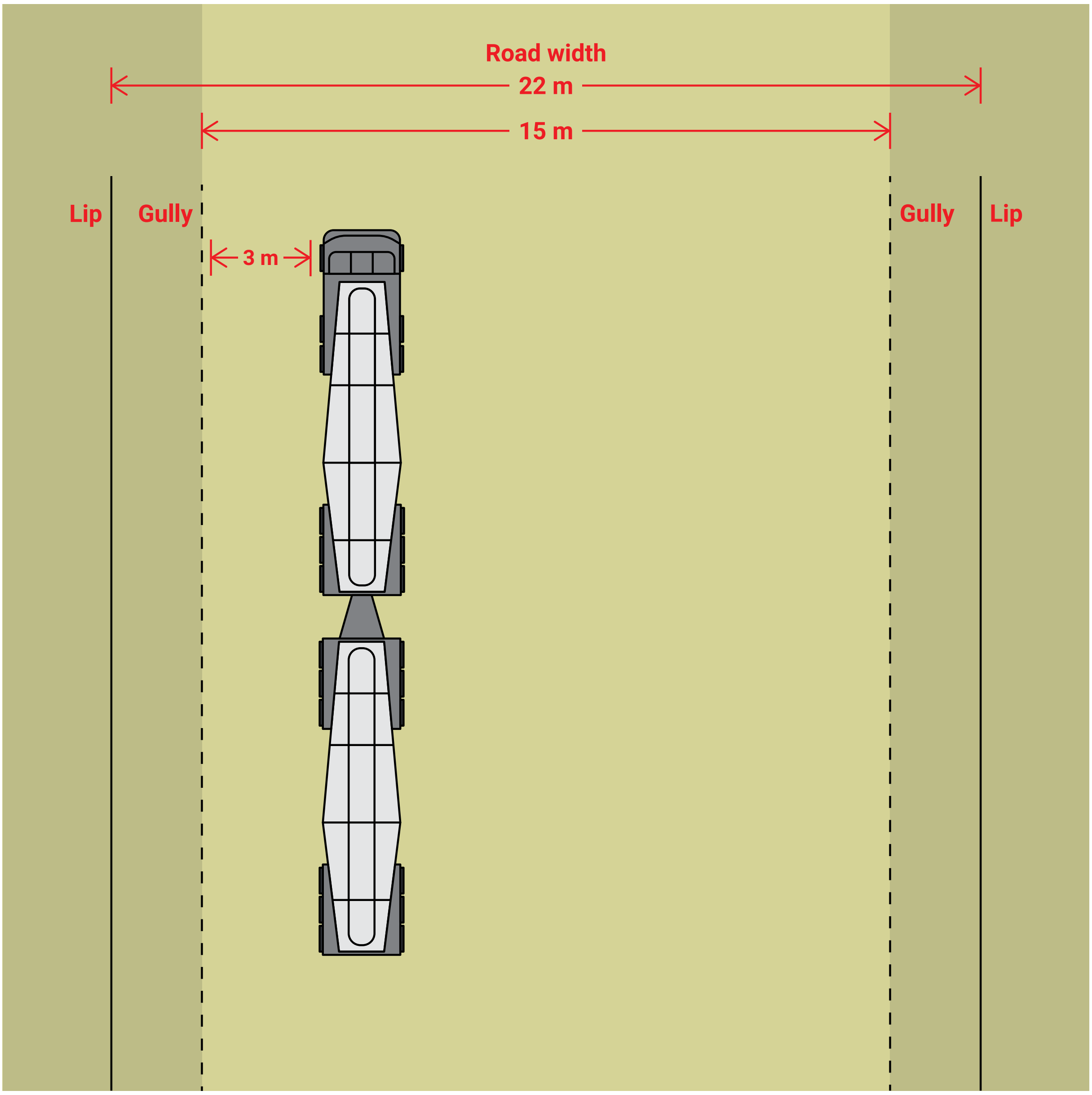


*Figure 4.4 Schematic of where the road train stopped and the road topography*

## 4.2 The fire

The driver exited the vehicle and was confronted with a fire on the passenger-side (LHS) tri-axle of the rear tanker trailer. He saw visible flames from the rear wheels of the two axles of the rear tanker (Figure 4.5). The flames quickly spread to the adjacent rear tyres and then to the front tyres of the rear tri-axle group. The height of the flames at this time were below the height of the mudguards.

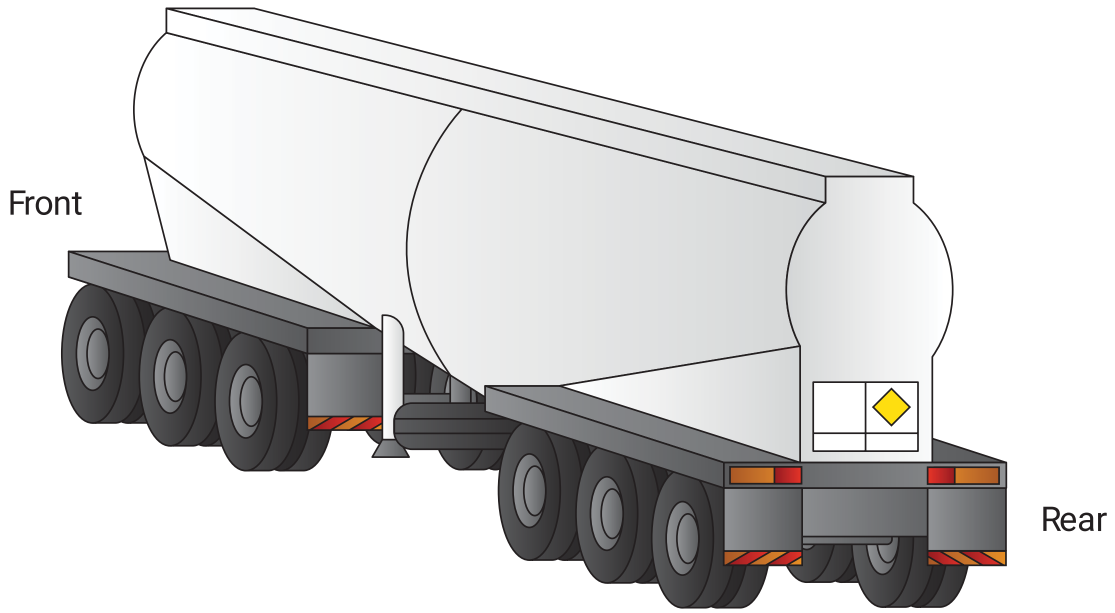


*Figure 4.5 Representation of the tanker trailer, demonstrating the four tyres on each axle (12 at the rear and 12 under the dolly at the front)*

*Note: Two spare tyres are mounted near the middle of the tanker.*

Before fighting the fire, the driver used his two-way radio to alert the other two drivers in the convoy that he had an emergency.

The driver initially used two 9 kg dry chemical powder fire extinguishers, which failed to extinguish the flames. He then proceeded to use his last remaining fire extinguisher, a 9 L water extinguisher. He squirted water onto the burning rear wheels on the passenger side from the opposite driver side by lying on his back with half of his body under the trailer, but was still unable to extinguish the fire. The driver did not utilise the additional reservoir of water (60 L) fitted to the driver side of the tanker trailer, noting the location of the hose was on the passenger side of the tanker.

## 4.3 Evacuation and subsequent actions

At 9:40 am, after unsuccessfully deploying all portable fire extinguishers and with flames already approximately 450 mm above the height of the mudguards of the tanker, the driver uncoupled the rear tanker and dolly. At 9:41 am the driver contacted one of the other drivers in the convoy and requested they contact the transport company and emergency services via their satellite phone, as no satellite phone was fitted to his vehicle.

At 9:45 am, leaving the burning rear tanker and dolly, the driver moved away from the scene with the prime mover and lead tanker, proceeding 3 km east to the turn-off to the Gruyere mine (Figure 4.6). The road is bitumised at this intersection.

The driver positioned the vehicle across the road at the intersection to block oncoming traffic from the east.

DFES coordinated the response to the incident, including liaising with the Local Government Authority (LGA), Gruyere Emergency Response Team and WA Police to minimise traffic to the affected area and establish a 2 km exclusion zone.

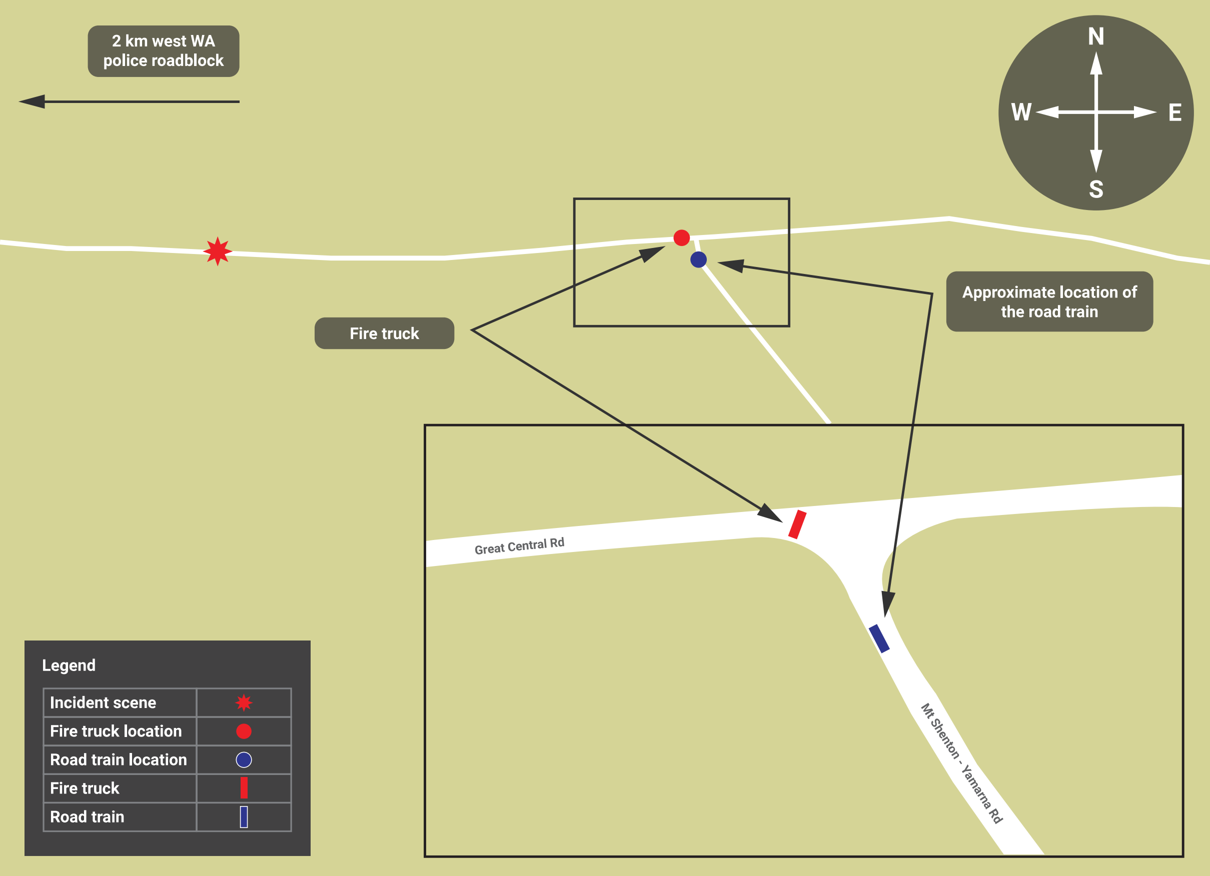


*Figure 4.6* *Representation of the location of vehicles at the incident scene (based on eye-witness recollection)*

The local authorities in Laverton also established a roadblock but nothing was put in place any closer to the incident site on the west side at this time.

At approximately 10:50 am, the Gruyere mine site emergency response team (ERT) arrived at the eastern road block and took over traffic management.

The driver left this site at approximately 11:15 am, proceeding to the mine site to deliver the remaining ANE in the lead tanker.

The Gruyere ERT tender entered the barricaded area at approximately 11:05 am and approached within 1,300 m east of the burning trailer to warn and usher a motorcycle and a vehicle out of the exclusion zone. The ERT reported they had a good line of sight of the front of the dolly: “It was well alight with fire coming from the ground and smoke changing colour from black to grey to white.” The driver of the vehicle travelling past the tanker mentioned to the ERT that the “tanker was well alight when he drove past.”

## 4.4 The explosion

The explosion occurred at 11:33:00.4 AWST (UTC + 8) on 24 October 2022 and was confirmed by GeoScience Australia, observing signals from infrasound stations located at Hobart (Tasmania), Tennant Creek (Northern Territory) and Shannon National Park (Western Australia). The Gruyere ERT felt the blast wave at their position 3 km away. They saw a large fireball spreading into the bush and a smoke plume/mushroom cloud rising approximately 1 km into the sky. Miners at the Gruyere site 25 km away (measured in a straight line) felt vibrations and noted windows rattling. This is similar to a normal mine blasting operation at the mine, except there was no blasting on site at that time.

*Figure 4.7 Image of explosion cloud captured by the ERT at 3 km from the blast facing a westerly direction (Credit: Gold Fields, Gruyere JV)*

*Notes: the orange cloud to the right of the cloud is highly likely to be Pindan dust, caused by the explosion. The road in shot is located near the intersection of the Great Central Road and Mount Shenton-Yamarna Road. The Great Central Road is bituminised approaching the mine turnoff on both sides.*

## 4.5 Response after the explosion

Immediately following the explosion the ERT were advised by DFES (the Hazard Management Authority who had control of the scene), not to enter the barricaded area.

At 12:17 pm, DFES instructed one of their officers to attend and render the site safe for entry.

At approximately 1:30 pm, Gruyere JV flew a drone to collect video imagery and survey the extent of the blast. Around this time DFES flew an aircraft over the crater to collect images of the incident scene. Spot fires and smoke were still present when both Gruyere's drone and DFES' aircraft flew over the incident scene.

By 3:00 pm, DFES and WA Police personnel had entered the scene and confirmed that there was no ANE remaining that could pose a safety hazard. Photographs were taken by DFES and WA Police of the crater. Following this, DFES contacted the LGA to coordinate backfilling of the road and reopened the road for vehicles for a short period of time. While there were disturbances by those involved in examining the site, it is unclear if the scene was disturbed further by any passage of vehicles.

Between 5:03-5:20 pm there were conversations between DFES and the LGA to close the road, so the scene could be secured to collect evidence.

A decision was made after a meeting with DFES (who had control of the scene), WA Police, LGA, Gruyere ERT and Department representatives to reopen the road, once detailed surveys were conducted by the mine site survey team. To reopen it, the road would need repair.

It is acknowledged that some evidence was disturbed and possibly destroyed due to reopening the road and backfilling the crater before the Department investigators had arrived at the scene. However, the road is of significant importance to mining services, aboriginal communities and travellers within the area, with little alternative for vehicles other than to detour for a significant amount of distance and time. The decision was made collectively to prioritise the reopening of the road over preservation of the scene for collection of evidence.

Surveys of the crater were completed on the morning of 25 October 2022. The road was backfilled and reopened by the early afternoon.

Dangerous Goods Inspectors arrive on scene at noon on 26 October 2022 to begin the investigation.

# 5 Site investigation and findings

The Department's investigation team arrival was at noon on 26 October 2022, 48 hours after the incident. The remote location of the incident prevented a faster response due to limited transport availability.

As noted previously, the Great Central Road is the main thoroughfare and reopening the road was a high priority. Keeping the road closed to perform extensive analysis on the crater was not practical and would cause operational issues at nearby mine sites and inconvenience to the local community and travellers.

The site therefore had not been preserved prior to the arrival of investigators. The crater was filled in before the investigation team arrived on site. Prior to the re-opening of the road, the crater was surveyed in detail by the mine personnel using drones. Some pieces of debris had been removed from the crater and placed nearby prior to it being backfilled. This resulted in a disturbance of the site by the road infill repairs. The initial evidence gathering and observations were done by other parties and the results of the surveys were made available to the Department.

## 5.1 The road

The incident occurred on a straight section of the Great Central Road. It ran straight for several kilometres in either direction of the incident. The unsealed road ran almost true in a west-east direction, only a few degrees off this bearing.

The road was raised in the centre, falling to a gully on each side with a sharp, steep rise (the lip) at the road verges. The road was lower and the lip was higher than the surrounding ground, which is important to explain the entrapment of the ANE later in the incident. The drop in height from the raised centre of the road to the bottom of the gully was 230 mm (Figure 5.1). This is typical for most gravel roads in Western Australia and is intentional to ensure water flows away from the centre of the road into drains graded on the edge into the dirt. In addition to this, over time the gravel and sand gets pushed by passing traffic to either side of the road.

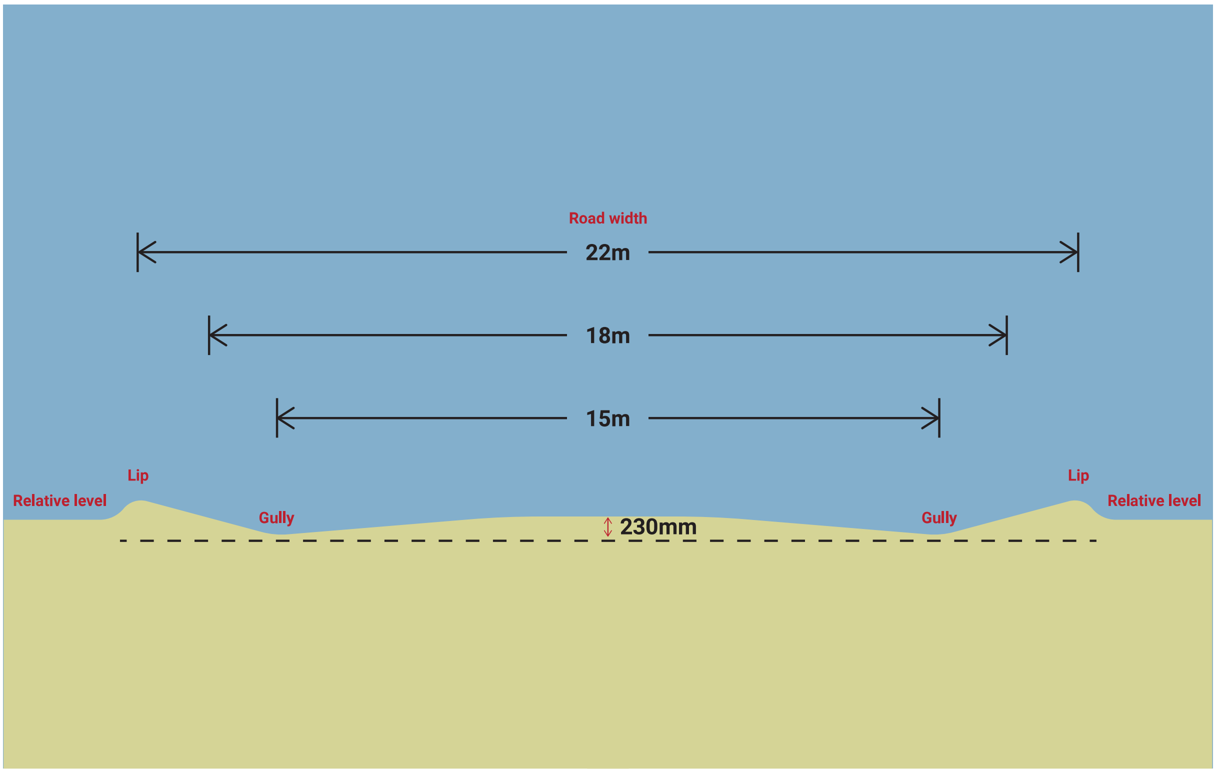


*Figure 5.1* *Schematic of the topography of a section of road. Measurements taken from road adjacent to where the crater was backfilled*

The width of the road was:

- 15 m from the gully on one side of the road to the gully on the other side of the road
- 18 m from mid-way on the rise of the lip to mid-way to the rise of the lip on the other side of the road
- 22 m from the top of the lip of the road to the top of the lip on the other side of the road surface.

Each lip of the road consisted of loose, dry sand. The road is constructed from Pindan sand (the name given to describe the sandy and arid red soil of the south-western Kimberly region of Western Australia), rocks and limestone from nearby rock quarries and was unsealed. It was in a poor condition with corrugations leading to the incident scene and the occasional rock protruding out of the road.

Laboratory results showed the road surface was comprised of minerals such as silicon dioxide and aluminium oxide as well as other trace metals such as iron and calcium.

There was a slight rise to both the west and the east in either direction for several kilometres. On a joint visit to the site, the driver confirmed that he pulled over at the lowest point in this section of the road.

*Figure 5.2 Photo of the road looking east (post backfilling of the crater) from the epicentre where it is slightly uphill*

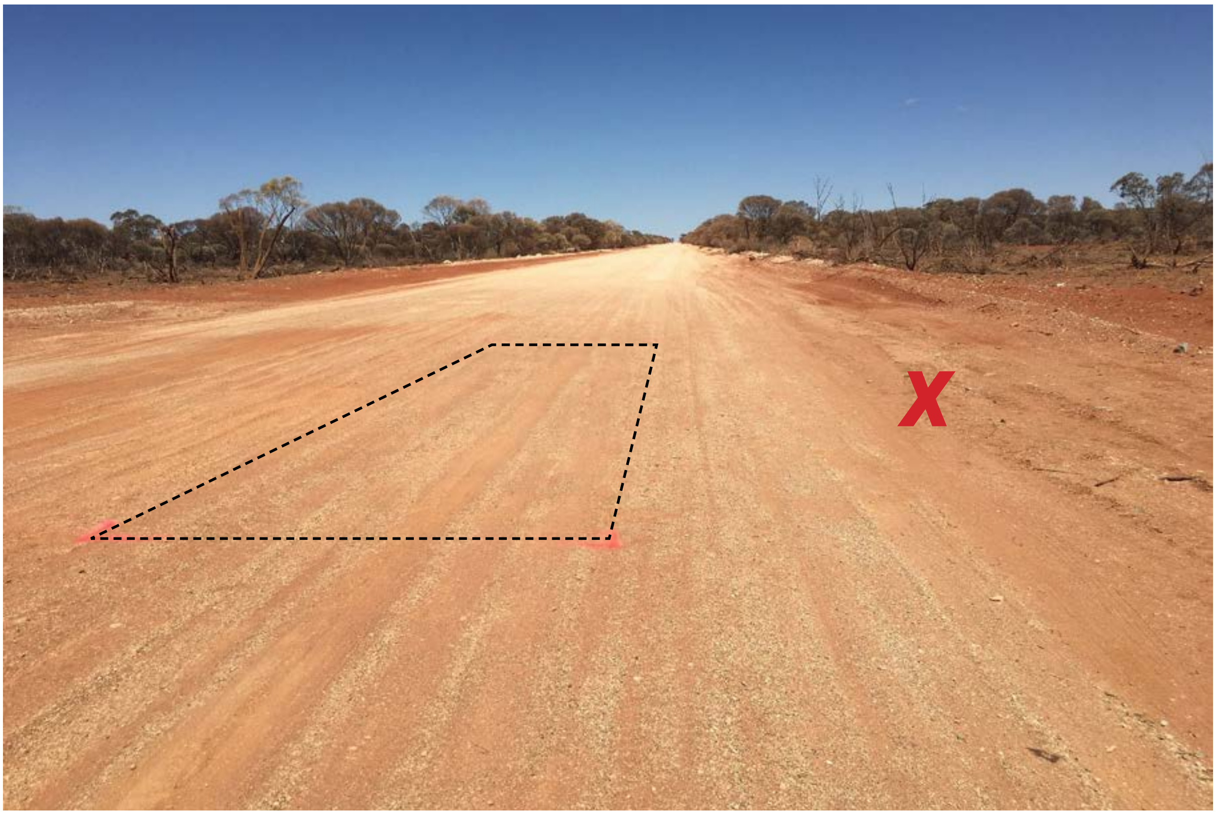


*Figure 5.3 Photo of the road looking west with a slight rise in the road. Note the markings indicate the location of the truck and the epicentre of the blast (red cross), prepared after consultation with driver at the scene*

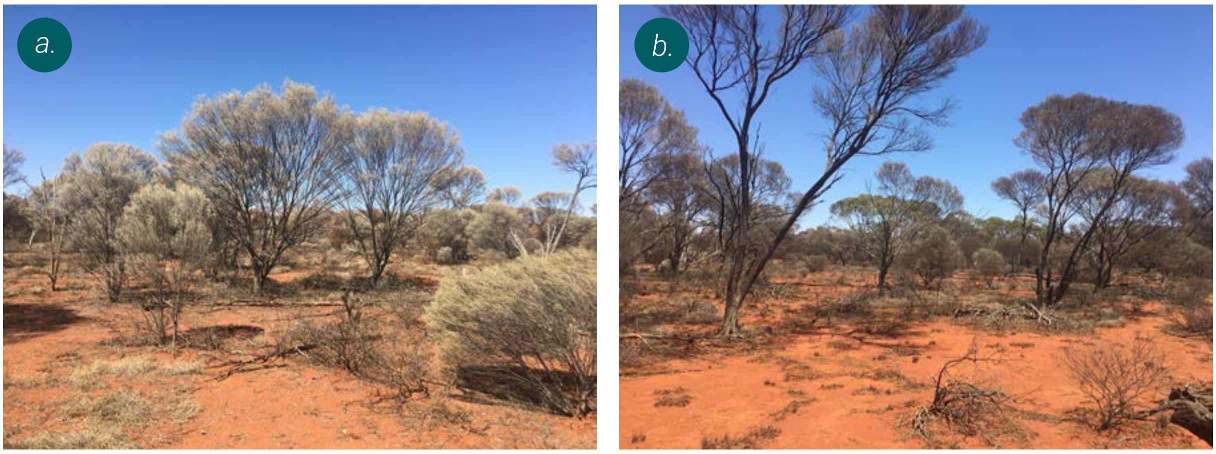
## 5.2 The surroundings

The road and surrounding land is under a native title claim by the Yilka Talintji Aboriginal Corporation.

The landscape surrounding the blast site consisted of red-orange Pindan soil. The land was flat with little undulation.

The landscape surrounding the blast site was moderately vegetated with small shrubs and trees.

An assessment of flora species within the area was provided by Gold Fields, Gruyere JV and Departmental environmental scientists. Trees were predominately mulga species (*Acacia aneura*) averaging 4 m high and ranging 2-6 m in height (Figures 5.4 a and b).



*Figures 5.4 (a) and (b)  Typical landscape surrounding the blast area, including some smaller trees and shrubs*

## 5.3 Blast effects

Three blast effects were observed:

- the nature and size of the road crater
- the type and extent of blast damage to trees and shrubs
- the nature and distribution of metal shrapnel and other debris from the tanker trailer and dolly.

*Figure 5.5* *Image captured from a drone approximately 2 hours after the explosion (Credit: Gold Fields, Gruyere JV)*

### 5.3.1 The crater

A crater was formed in the road as a result of the blast. It was large and shallow with the deepest point being approximately 1.1 m deep. The crater was irregular in shape, very roughly elliptical, 17 m in a west to east direction and an average of 9 m in a north to south direction with a total area of approximately 120 m² (Figure 5.6). These measurements were captured by Gold Fields, Gruyere JV using survey equipment. It should be noted that initial measurements reported (in the Safety Alert) were an early observation and overestimated the crater size.

Figure 5.6 shows the approximate location of the tanker trailer, as described by the driver, superimposed on a survey image of the crater.

The shape and size of the crater and the location of the tanker trailer in relation to the crater is consistent with the expected spread/flow and final position of the ANE, as explained in section 5.1 and chapter 9.

The location of the centre of the crater in relation to the tanker in Figure 5.6 is consistent with the location and trajectory of the metal debris that was found described in section 5.3.3.3 and is evidence of a ground-based explosion.

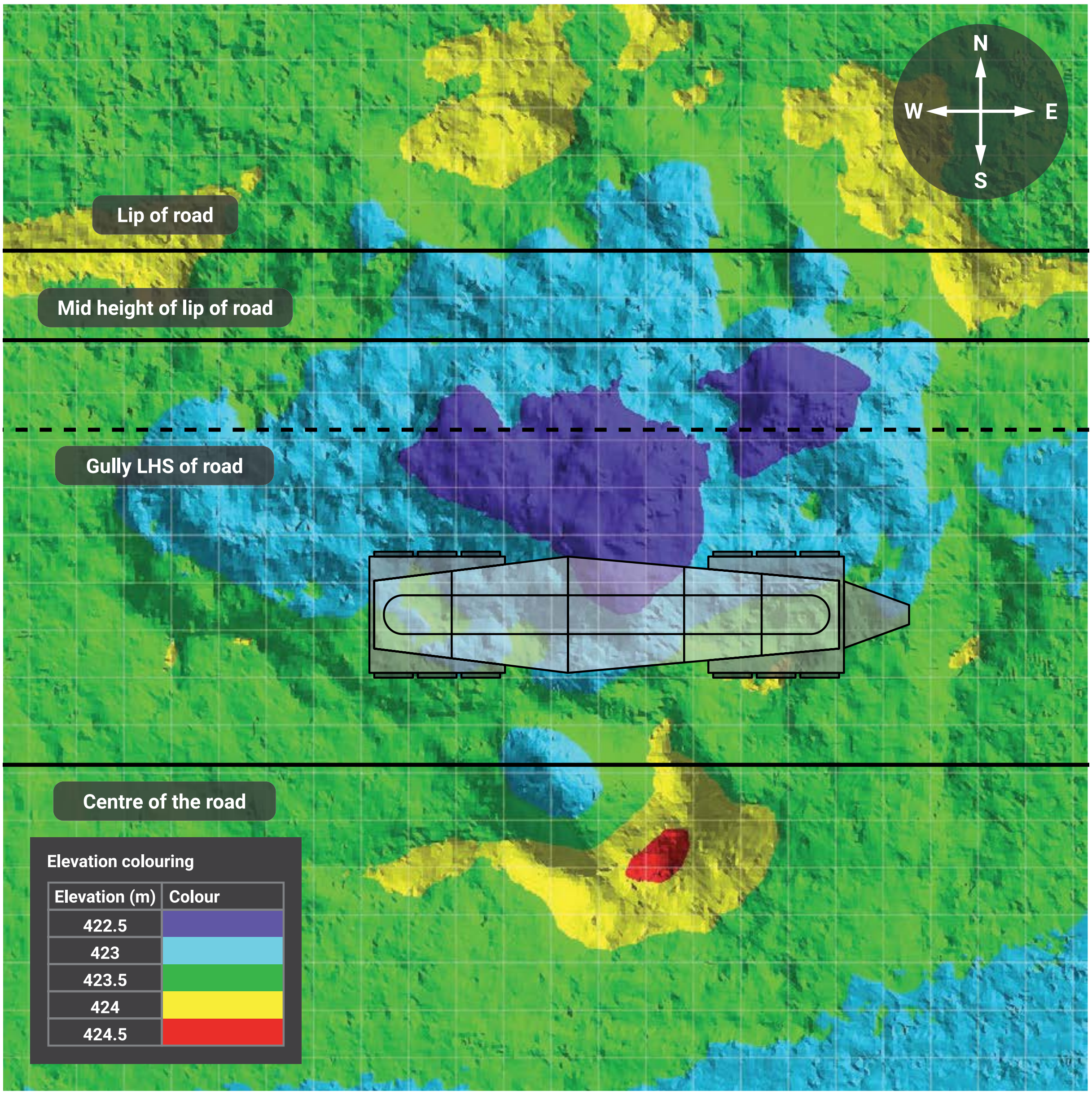
From the evidence gathered at the scene and explained in section 5.3.3 and Chapter 9, it is assessed that there was a loss of containment of ANE, as a result of the tyre fire melting a hole in the aluminium tanker shell. The ANE pooled beneath the tanker trailer and became trapped within the gully of the road. Based on the evidence collected, in particular the distribution of large pieces of steel debris from the dolly to the south east of the crater, this indicates that the blast most likely initiated at the middle to rear of the tanker trailer where the most product pooled (trapped by the gully).

Had the explosion occurred within the tanker itself, the location of the crater would be underneath the centre of the tanker and the debris pattern would be very different, that is, more evenly distributed shrapnel in all directions across the debris field and closer to the crater.

It is likely that the size of the crater area is somewhat smaller than the initial spread of the ANE, because the ANE at the crest of the road and the edges of the pool would be too thinly spread to sustain a detonation. A significant portion of the ANE would also have decomposed by the time of the explosion, reducing the size and volume of the pool.

The shallowness of the crater is also likely because of a low velocity detonation (VOD), indicating poor performance of the explosive substance. Generally speaking, an explosive with a high VOD would form a deeper crater, with a steeper angle to the bottom, while a low-energy, low VOD explosion would form a shallow crater.

It should be noted that no ANE or AN was observed at the crater site prior to the backfilling, or after the site was examined more closely by the Department investigators.



| Elevation (m) | Colour |
|---|---|
| 422.5 | 🟪 |
| 423 | 🟦 |
| 423.5 | 🟩 |
| 424 | 🟨 |
| 424.5 | 🟥 |

*Figure 5.6* *Survey of the crater performed by Gold Fields, Gruyere JV. Overlaid is the estimated location of the tanker and dolly (Credit: Gold Fields, Gruyere JV)*

*Note: Each square represents 1 m x 1 m. Changes in colour are representative of 0.5 m depth change.*

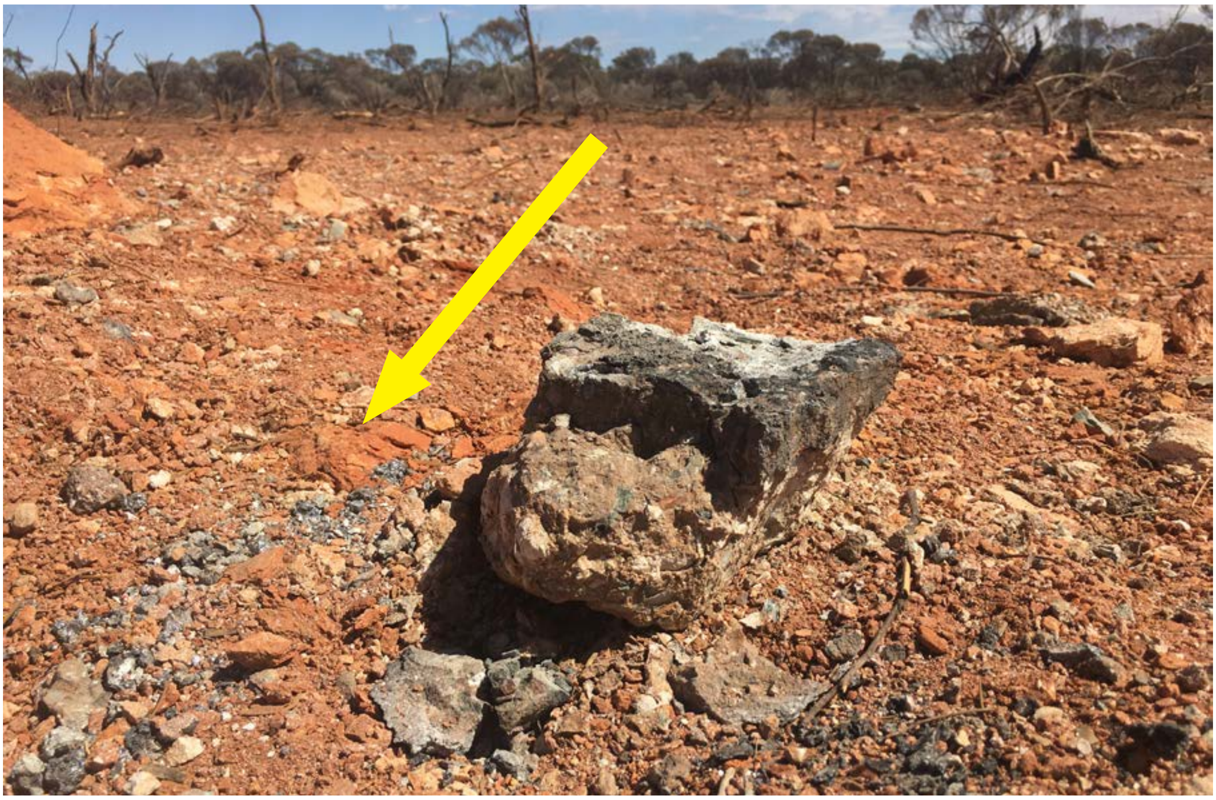


Figure 5.7 *Image of sprayed rock (taken on northern side of road looking roughly north-north-west. Arrow points to molten aluminium. Large rocks are from the road surface. The surface next to the road is otherwise very sandy*

Figure 5.8 *Aerial drone image capturing the crater and the spray of rocks from the road, most pronounced, to the north of the crater (Credit: Gold Fields, Gruyere JV)*

The incident took place at an elevation of 422.5 m and 424.5 m above sea level. The blast produced a 'spray' of rocks and road base in a northerly and southerly direction and perpendicular to the road to a distance of 30 m. The 'spray' of rocks contained solidified molten aluminium and small conglomerates of molten aluminium and road base (see Figures 5.7 and 5.8). The spray of rock was more pronounced to the north because of the steep north lip of the road, in contrast to the shrapnel distribution which was more pronounced to the south (see section 5.3.3).

A number of photos were taken by DFES and WA Police prior to the backfilling of the crater and opening of the road (Figures 5.9, 5.10, 5.11 a and b). Some of these images show large lumps of solidified molten aluminium in the crater and small pieces of vegetation. It is likely that the vegetation in the crater was sucked in from the vacuum that followed the blast overpressure.

Solidified molten aluminium is indicative that melting of the aluminium tank shell had occurred due to an intense fire prior to the explosion. A large piece can be seen within the crater from the images taken (Figures 5.10, 5.11 a and b). The density of molten aluminium is approximately 2.7 grams per cubic centimetre (g/cc) and would have pooled under the lighter decomposing AN mixture. Some of this aluminium was found within the crater following the explosion.

*Figure 5.9 Vegetation within the crater following the blast overpressure (Credit: WA Police)*

Figure 5.10 Image of crater looking east. Note solidified molten aluminium can be seen to the bottom left of the image (Credit: DFES)

Figure 5.11 a Image of the crater looking north-west (Credit: DFES)

Figure 5.11 b Zoomed in image of solidified molten aluminium (Credit: DFES)

*Figure 5.12 Solidified molten aluminium, located close to road when the investigation team attended site*

### 5.3.2 Blast overpressure

The blast overpressure damaged the surrounding bush. Two distinct concentric circles of blast damage were evident (Figure 5.13).

Trees and shrubs to a distance of approximately 40-50 m were completely flattened and some trees up to 7 m high were uprooted by the blast (Figures 5.13 and 5.14). Another wider concentric circle extended up to 120 m from the crater and consisted of snapped branches, 75-110 mm thick. Beyond 120 m, the overpressure was too weak and branches were sufficiently flexible to remain intact.

The ERT members at the roadblock stated they felt the blast overpressure 3 km from the incident scene and the blast wave rocked their vehicle. Some mine workers located at the Gruyere site approximately 25 km in a direct line from the incident felt vibrations and noted windows rattling.

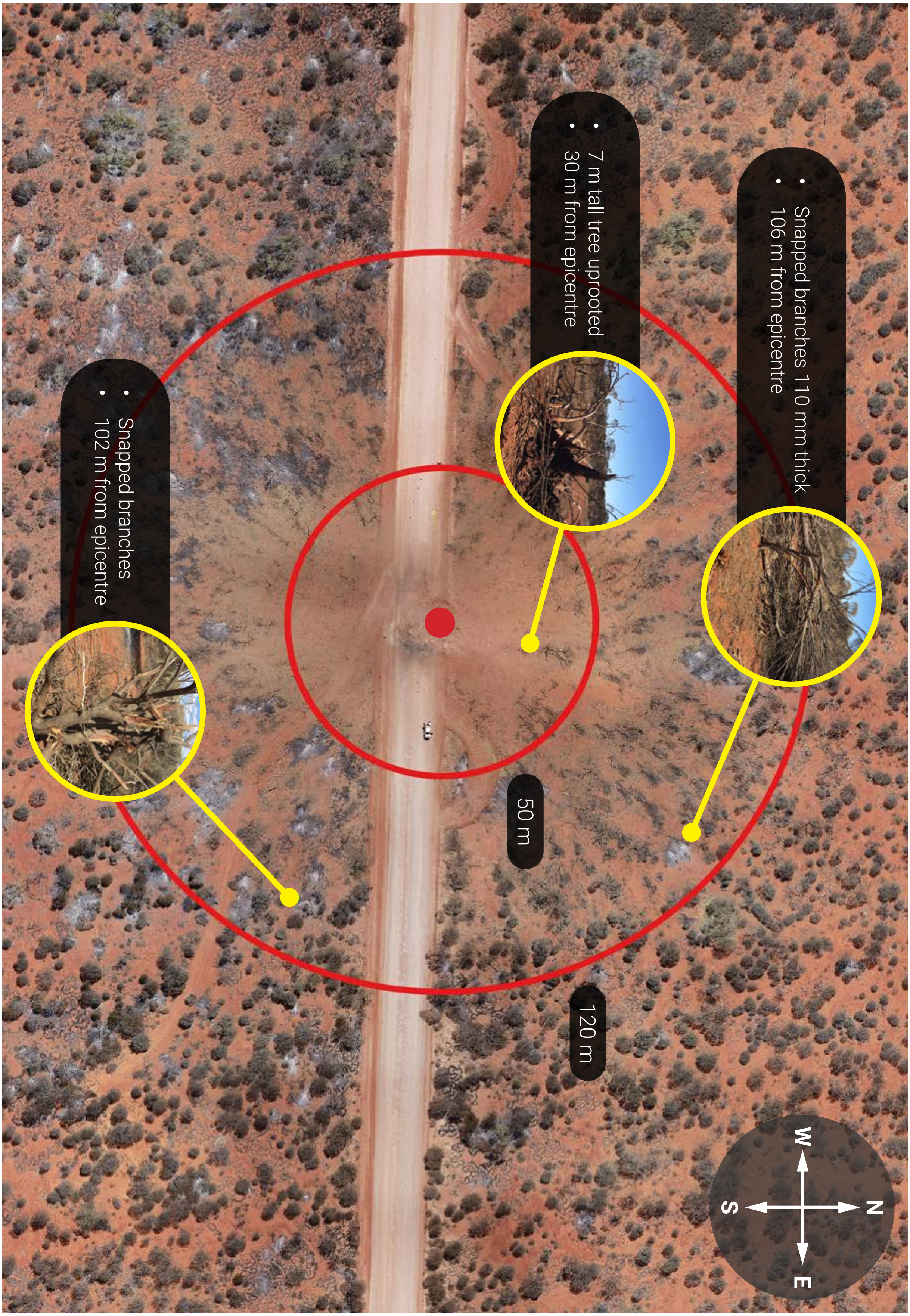


*Figure 5.13* *Blast overpressure effects on the surrounding landscape. Two distinct circles were formed, markers here are at 50 and 120 m from the epicentre (Credit: Gold Fields, Gruyere JV; annotated by the Department)*

*Figure 5.14 Photo of uprooted tree 7 m high located 30 m from the epicentre of the explosion*

*Figure 5.15 Photo of trees destroyed by the blast up to 50 m from the epicentre (up to 125 mm diameter trunks)*

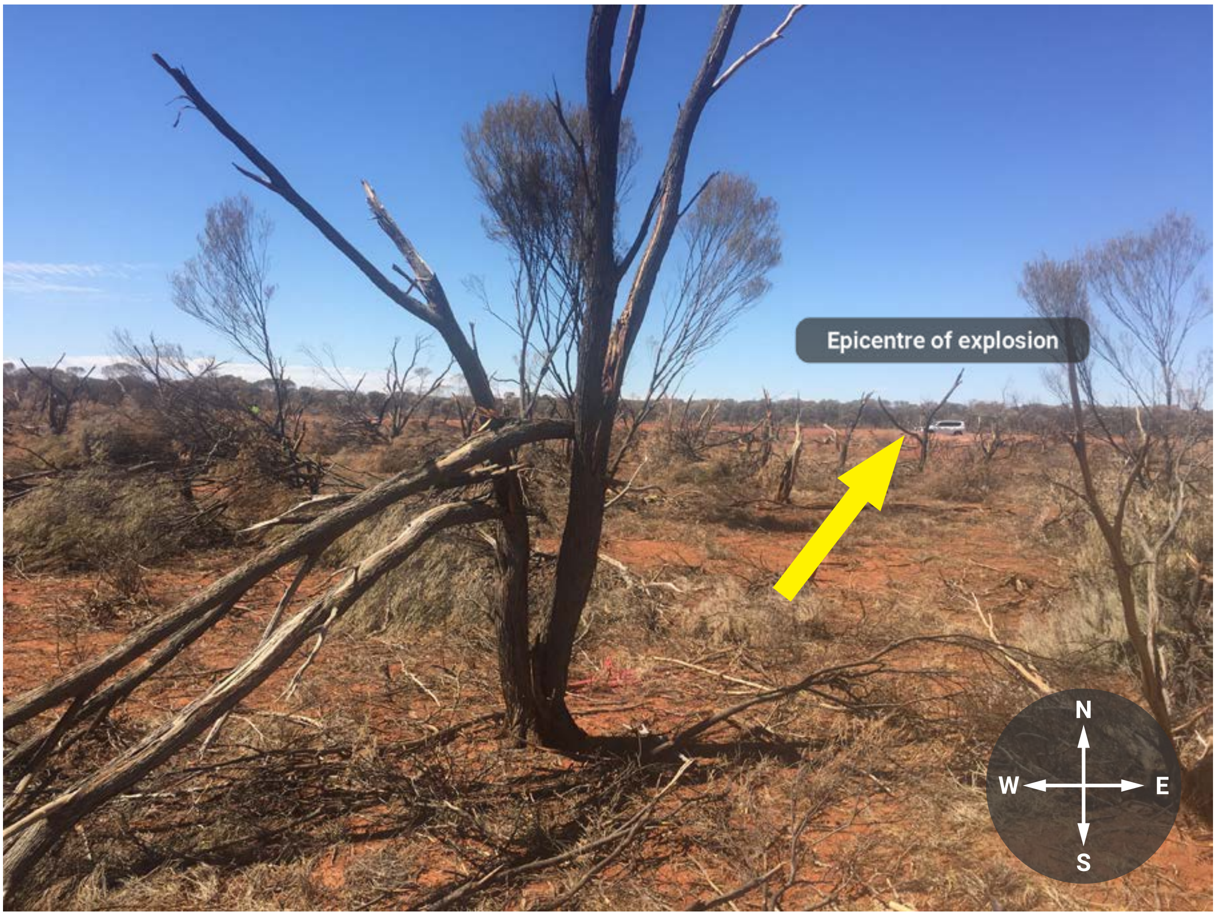


*Figure 5.16* *Photo of trees damaged by the blast at 100 m from the epicentre. Branches 110 mm in diameter branches are snapped. Arrow indicates location of epicentre*

### 5.3.3 The debris field

The blast produced thousands of pieces of shrapnel, which were scattered predominately to the south of the road. The investigators made an early decision not to catalogue every piece of shrapnel, given the wide debris field, the hot weather conditions and remoteness of the site, leading to a focus on capturing the overall details of the scene. There was an effort placed on identifying large and significant pieces of shrapnel and understanding the distribution and nature of the blast debris. The findings from the evidence at the scene have informed the likely cause of the explosion and recommendations on appropriate emergency responses, including evacuation distances.

The types of shrapnel and debris found at the incident scene included:

- clean globules of solidified molten aluminium
- solidified molten aluminium that was embedded into the ground from impact and/or cooling
- thin aluminium pieces with jagged edges from the intact part of the shell of the tanker
- aluminium checker plate mounted to the top of the dolly
- pieces of steel from the chassis and running gear (wheels, axles, etc.) of the trailer and dolly
- pieces of shredded rubber from the tyres including some burnt and unburnt fragments
- air supply line and electrical cabling.

Significant pieces found were mapped using GPS coordinates (using a hand-held GPS and mobile phone metadata from images taken), photographed and weighed to provide information on the location, type and distribution of the shrapnel (Figure 5.17). The Department sought assistance from the tanker trailer manufacturer when attempting to identify discernible pieces of the tanker trailer and dolly.

### 5.3.3.1 Overview of the distribution of the pieces of shrapnel and debris

A focus on locating, identifying and measuring key pieces of shrapnel and debris was undertaken to gain insight into understanding the nature of the explosion, and where it may have occurred in relation to the vehicle.

Shrapnel was found within the crater (0 m) and out to 750 m.

The spot fires were caused by the hot shrapnel. The search took place over an area extending 100 m past the edge of the spot fires (in all directions), which meant the search area was not a consistently measured distance from the crater.

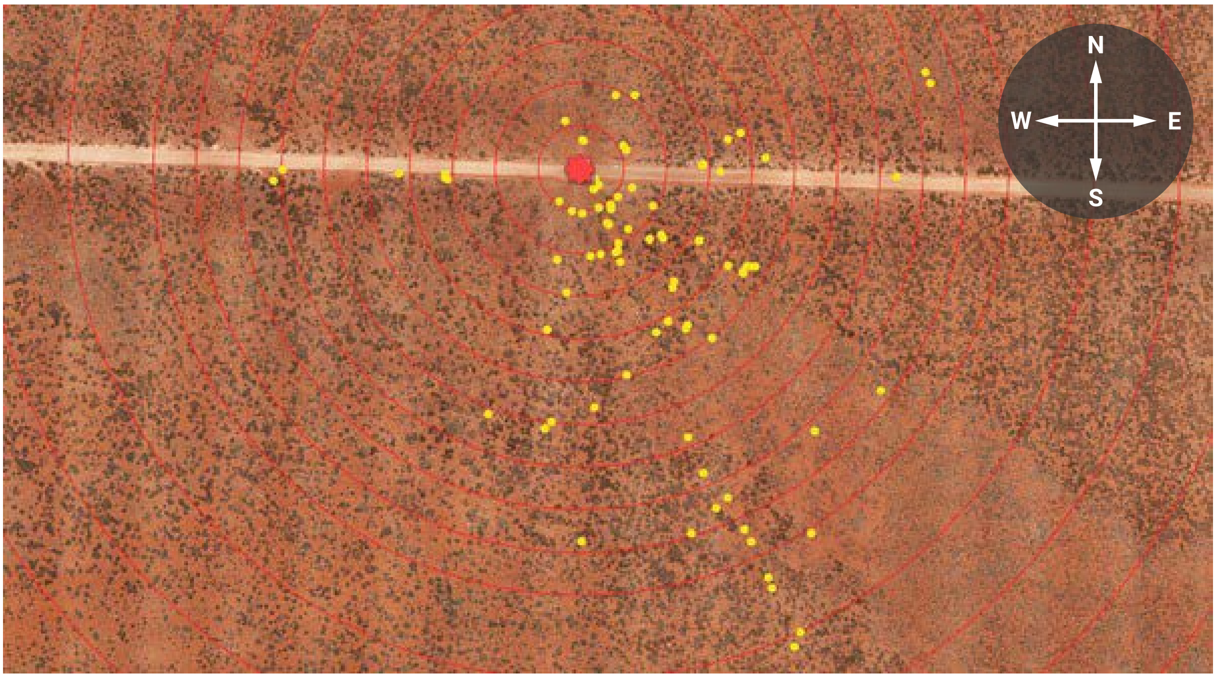


*Figure 5.17* *Distribution of significant shrapnel and debris (includes aluminium, steel and other debris) located at the incident scene represented in yellow. The red marker indicates epicentre of explosion. The red circles indicate the distance in 50 m intervals to 500m from the epicentre of the explosion, and then at 100 m intervals from then on (Credit: Gold Fields, Gruyere JV; annotated by the Department)*

Figure 5.17 demonstrates the general scattering of debris that was distributed across the debris field. The sizes of the shrapnel varied from very small pieces of aluminium metal (less than 10 cm²) to large chunks of steel (weighing upwards of 100 kg).

The majority of the shrapnel pieces and other debris were concentrated to the southern side of the road (estimated to be 95% of the total number of pieces of shrapnel). This is consistent with the location of the main blast being on the passenger side of the tanker trailer.

Of the smaller amounts of shrapnel located on the north side of the road, the majority were located within 50 m from the epicentre of the explosion.

A summary of the density of debris is provided in Figure 5.18. This demonstrates the change in debris characteristics and distribution across the debris field. The density and the types of debris found at these locations provides evidence of the following:

- parts of the tanker shell had melted and formed molten solidified aluminium (estimated greater than 50 kg found). This indicates a loss of containment and melting of the ANE tanker caused by the fire that continued to burn for two hours before the explosion
- parts of the tanker shell were intact when the explosion occurred. There were small pieces of aluminium (less than 10 $cm^2$) found beyond 200 m. This indicates that large portions of the tank shell was in direct contact with ANE at the time of the explosion, as detailed in the findings of the Norwegian Directorate of Civil Protection's project committee's report *Explosion Accident during Mobile Production of Bulk Explosives* 2013 (the DSB report)
- larger pieces of steel were found at distances of greater than 250 m with some pieces embedded within the ground. This supports the location of the explosion to be a ground-based explosion, where the blast trajectory forced steel upwards.

It is clear that the majority of the tanker shell was intact when the explosion occurred, due to the significant amount of thin aluminium pieces (between 6-8 mm) spread across the debris field, however it is unclear if it was still upright at the time. It is possible that part or all of the aluminium shell structure collapsed, due to the intense and prolonged heating from the fire. This may explain the northern location of some of the aluminium pieces and would explain why small pieces of aluminium were propelled so far away (greater than 200 m).

An investigation into the MPU fire in Norway as detailed in the DSB report (see section 7.1) found it likely that small pieces in direct or close contact with ANE would be propelled significant distances, as we have also found at the Great Central Road incident. With most of the ANE pooled on the road and the low clearance of the tanker, it is considered that the belly of the tanker was in direct contact with the pool of molten sensitised AN at the time of the explosion.

| Distance of concentric circle (m) | Bearing | Number of pieces found within survey sample | Comment |
|---|---|---|---|
| 50 | North | Less than 1 | Mostly jagged aluminium, some molten solidified aluminium and very few small steel pieces between 30-50 m (less than 300 g) |
| 100 | North | Less than 1 | Mostly small steel pieces |
| 50 | South | 4 – 6 | Mostly jagged aluminium pieces, some molten solidified aluminium |
| 100 | South | 9 – 12 | Mostly jagged aluminium pieces |
| 150 | South | 5 – 8 | Mostly aluminium with shrapnel becoming larger in size |
| 200 | South | 8 | Mostly aluminium with increasing number of steel pieces. Significant number of small aluminium pieces less than 10 cm². |
| 250 | South | 1 – 4 | Shrapnel becoming larger in size. Aluminium shrapnel size less than 10 cm². |
| Greater than 250 | South | Less than 1 | Mostly large steel pieces found at large distances (greater than 5 m) from other pieces. Some large pieces of jagged aluminium and molten solidified aluminium. |

*Figure 5.18 Description of debris field*

*Note: A 1 m by 1 m survey was undertaken of the number of pieces, at 50 m concentric intervals.*

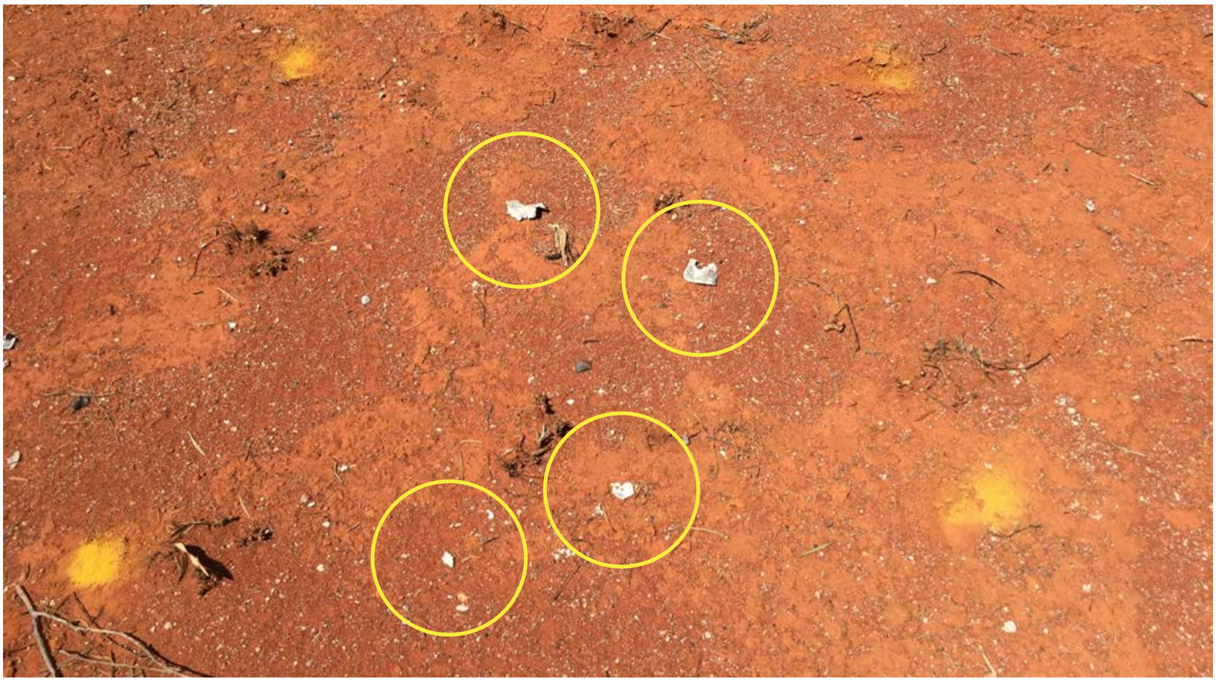


*Figure 5.19 Example of 1 m by 1 m survey located at 250 m south of the epicentre. There were other pieces of aluminium (from the tanker shell) less than 10 cm² per m²*

*Note: The camera angle does not accurately depict the 1 m square.*

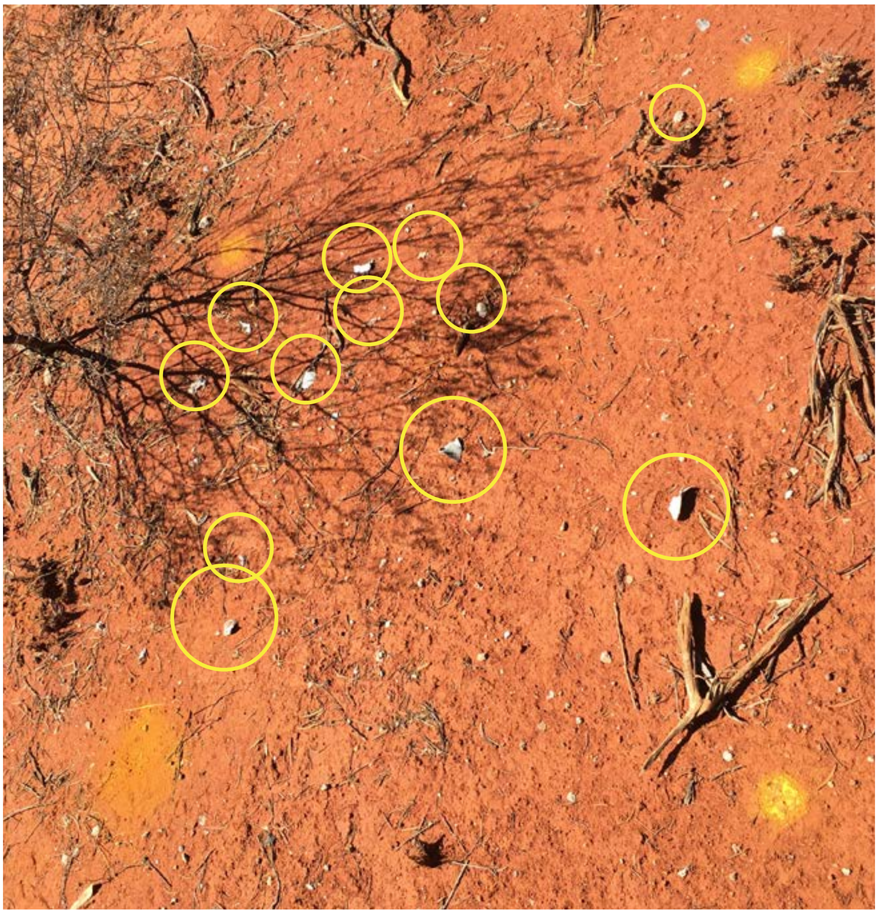


*Figure 5.20 Example of 1 m by 1 m survey located at 110 m south of the epicentre. There were twelve pieces of aluminium (from the tanker shell) less than 10 cm² per m²*

*Note: The camera angle does not accurately depict the 1 m square.*

#### 5.3.3.2 Analysis of the scattering of aluminium pieces

An examination of aluminium pieces was undertaken to understand the damage to the aluminium tanker shell and dolly. A significant number of aluminium pieces were found at the incident scene, with many thousand pieces found near the epicentre unaffected by heat. These varied in size from a couple of grams to several kilograms. Solidified molten aluminium was also found close to and within the crater as well as up to 310 m away (Figures 5.10, 5.11 a and b and 5.12).

Aluminium was found in different forms including

- solidified molten aluminium that cooled on the ground and was impregnated with gravel and dirt
- clean globules of solidified molten aluminium
- aluminium pieces with jagged edges from the intact shell of the tanker
- aluminium checker plate originally mounted on the top of the dolly.

The solidified molten aluminium pieces appeared to have melted from the tanker shell and possibly the wheel rims and cooled on the ground before being propelled by the explosion. They were flat and plate-like and impregnated with soil and small pieces of rock on one of the two flat surfaces (Figure 5.21). The surface of these pieces appear pitted and irregular in shape.

Some pieces appear to be smooth in appearance and are not impregnated with soil or rock (Figures 5.21 and 5.23). It is possible that this may have been the result of cooling of molten aluminium on the steel chassis or pieces of softened aluminium from the edge of the hole of the tanker shell where it became caught up in the fireball of the explosion.

Other pieces of aluminium, from the tanker shell, did not appear to be affected significantly by heat. It is known they were from the tanker shell as they were thin aluminium plate with jagged edges. Some were more softened and had become extruded and buckled due to the heat and forces of the explosion.

A number of large pieces of checker plate originally mounted on the top of the dolly were also located to the east-south-east of the epicentre at approximately 104-212 m in a similar trajectory.

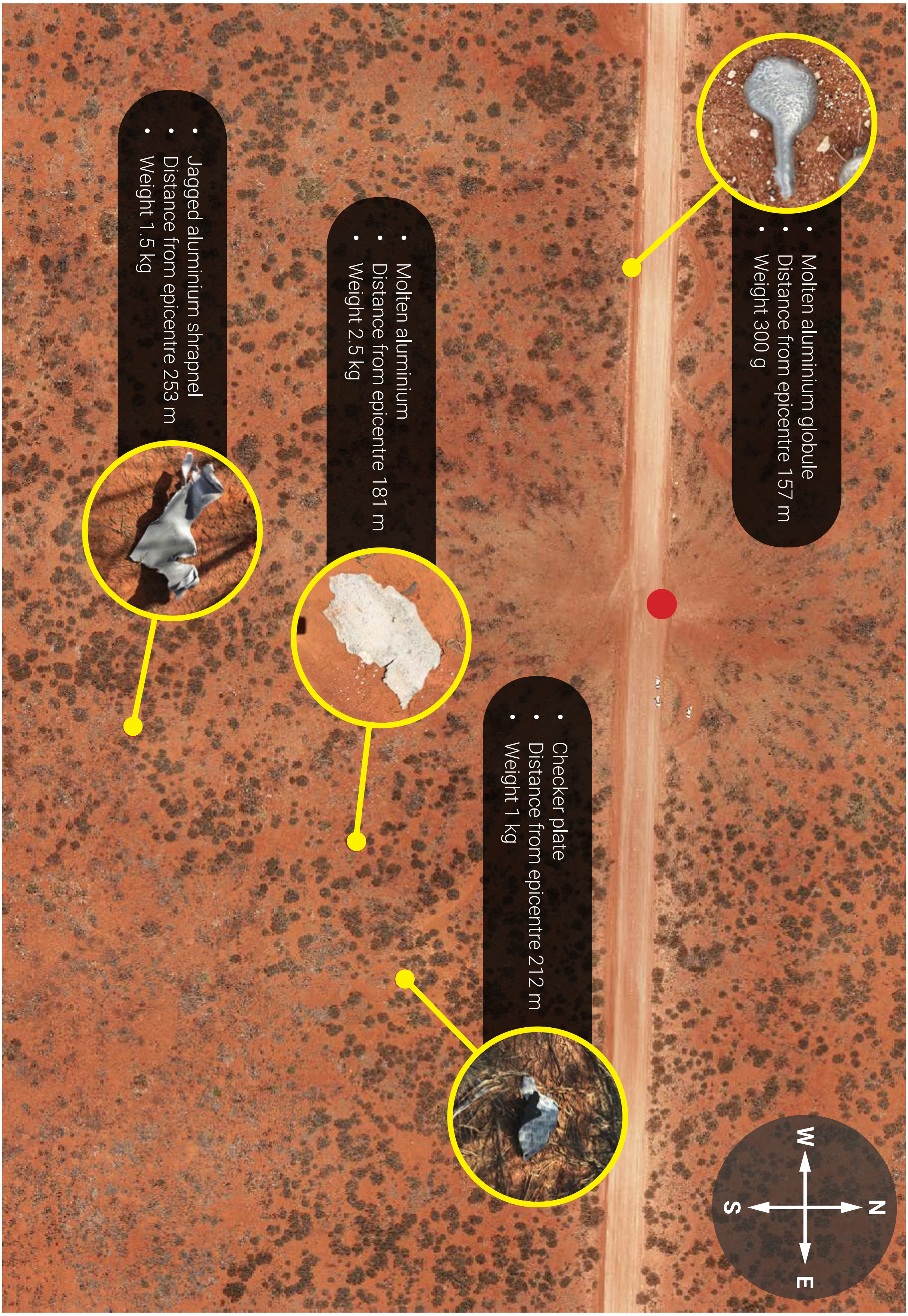


*Figure 5.21* *Various forms of aluminium shrapnel found at the scene, weight and location from the epicentre of the explosion. The red marker indicates epicentre of explosion (Credit: Gold Fields, Gruyere JV; annotated by the Department)*

Figure 5.22a *Aluminium fragment from intact section of tanker shell found to the south-south-east of the blast*

Figure 5.22b *Aluminium shrapnel found at approximately 50 m to NW of the epicentre of the explosion*

Figure 5.23 Image of molten aluminium pieces approximately 10 cm in length located 157 m west of the epicentre

Figure 5.24 Another piece of solidified molten aluminium, pitted by the cooling on the ground and formed into a ball like structure

#### 5.3.3.3 Analysis of the scattering of steel pieces

The largest and heaviest pieces of steel shrapnel were located on the southern side of the road. The explosion had a significant effect on the tanker trailer and dolly and it was challenging to identify discernible pieces of either the tanker trailer or the dolly without assistance from the tanker manufacturer.

The following are details of notable pieces of shrapnel, their location and their significance in providing evidence of the events that occurred.

- A brake drum weighing 60 kg was found 97 m in a south-east direction from the blast site (Figures 5.25 and 5.26). It was not buried, indicating that it had a low trajectory when it came to rest. Its position is consistent with being part of the dolly.
- A piece of an axle suspension arm weighing in excess of 100 kg, was found 420 m in a south-east direction (Figures 5.25, 5.28 a and b). This piece had landed and bounced 3 m to its final location being stopped by a tree. Its position is consistent with being part of the dolly.
- A piece of the dolly turntable weighing 31 kg was found 672 m south-south-east from the epicentre (Figures 5.25, 5.27 a and b). It was 90 % buried at the time it was found, indicating it had a high trajectory, consistent with being propelled (lobbed) by an explosion underneath it.
- Several semi-submerged pieces of steel to the south-east of the epicentre 232 m from the epicentre.
- A mudguard support, weighing approximately 25 kg was found 329 m in a south-east direction from the epicentre (Figures 5.25). It is also thought to have been from the dolly.
- A fragment of a wheel hub was found in a similar trajectory to the axle suspension at 230 m. An unexpected finding was that no other wheel hubs were found, considering there were 26 wheels in this configuration.
- Part of an axle hub located south of the explosion at 266 m (Figure 5.25).
- Pivoting mounting plate for the dolly landing leg was located at 240 m south-east from the epicentre (Figure 5.25).
- Part of a brake drum and a brake booster approximately 140 m south-south-east of the epicentre of the explosion.
- There was some evidence of steel pieces having been weakened by the temperatures of the fire (Figure 5.29), located at 304 m in a south-south-east direction.

The most significant pieces of steel found appear to have mostly originated from the dolly. This indicates that it is likely the source of the detonation event was near the rear or middle of the tanker trailer and was ground-based.

It should be noted that the following were not found at the explosion site:

- 25 of the 26 wheel hubs
- any other large pieces of steel (larger than 1 m)
- vents from the tanker
- the discharge pipe.

Little of the steel debris was found, which was unanticipated. It is possible that the explosion ripped most of the steel components into small enough pieces that they were destroyed or disappeared into the soft sandy soil.

It should be noted that attempts were made by investigators to secure an alternative drone with a magnetometer in order to locate as many pieces of shrapnel as possible, however, expert advice provided was that the small size of the thousands of pieces were unlikely to be located or able to be mapped by the device. As a result, it is possible some pieces were not located within the original search area.

An additional drone was deployed on the second visit to site that mapped a more extensive area 1 km by 1 km. Analysis of this imagery did not yield any further evidence of significantly sized debris. It did however provide the basis for a number of images and mapping of shrapnel detailed within this report.

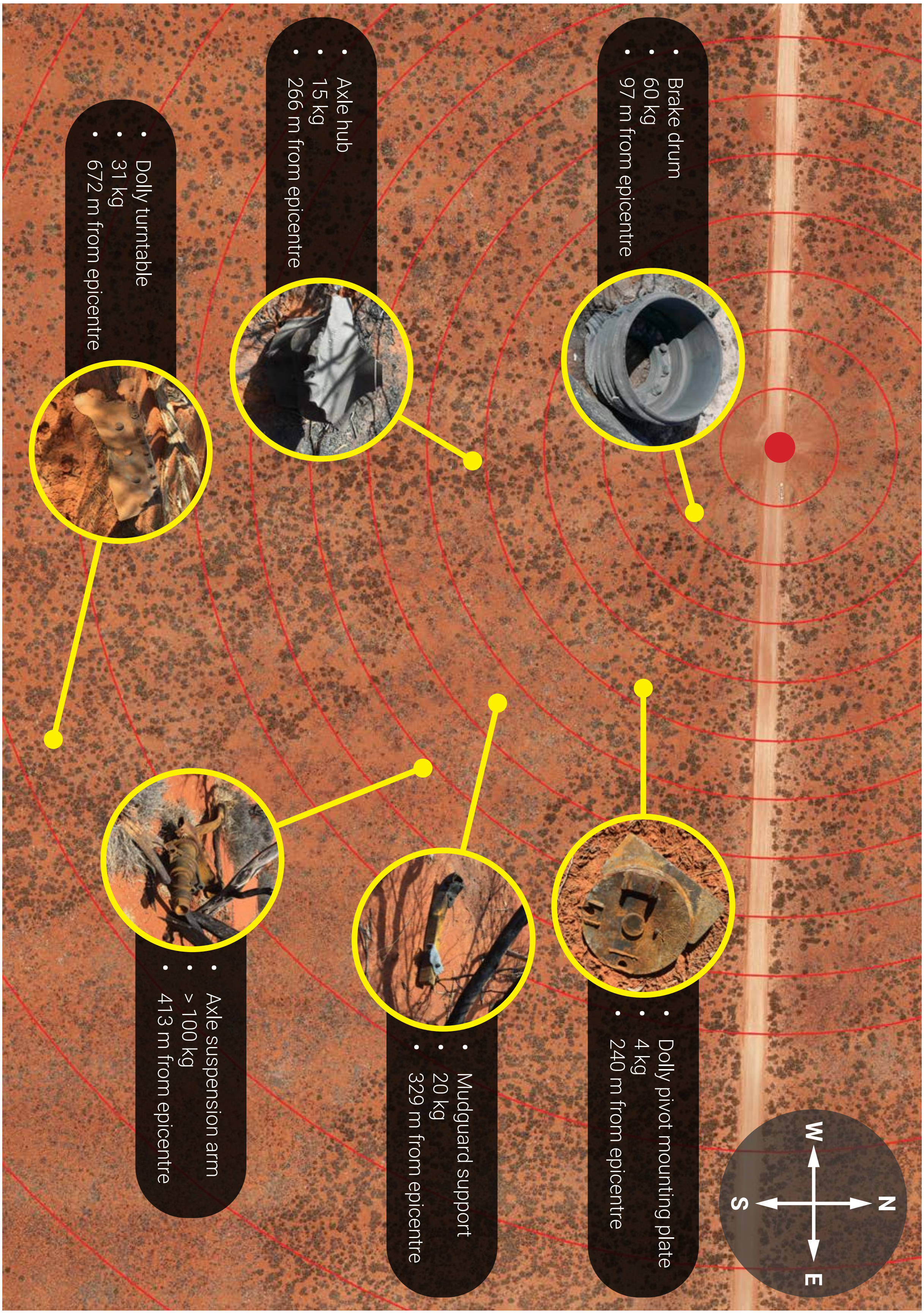


*Figure 5.25* *Significant and identifiable steel pieces located at the incident scene. The red marker indicates epicentre of explosion. The red circles indicate the distance in 50 m intervals to 500 m from the epicentre of the explosion, and then at 100 m intervals from then on (Credit: Gold Fields, Gruyere JV; annotated by the Department).*

Figure 5.26 Brake drum weighing 60 kg located 97 m south-east of the epicentre of the blast

Figures 5.27 a and b Piece of dolly turntable, weighing 31 kg, found embedded within the ground at 672 m from the epicentre of the explosion

*Figures 5.28 a and b  Axle suspension arm from dolly (weighing in excess of 100 kg)*

*Note: The disturbed ground approximately 3 m to the north of it. Located 420 m from the epicentre of the blast.*

*Figure 5.29* *Steel piece of shrapnel (approximately 20 cm) with noticeable softening effects on the edges from the fire. Piece located at 304 m south-south-east of the epicentre of the explosion*

#### 5.3.3.4 Analysis of other debris

There was little physical evidence of the tanker trailer and dolly at the epicentre of the explosion. However, evidence of other debris providing information on the progress of the fire and resulting explosion was found.

The following were observed:

- fragments of burnt tyre rubber indicating that some tyres had been involved in the fire (Figure 5.33)
- several fragments of unburnt tyre rubber were found indicating not all tyres had been completely consumed at the time the explosion occurred
- steel radials from within the tyres indicating the rubber hydrocarbon surrounding the tyre had been consumed (Figure 5.30)
- there was some evidence of fire damaged material, including melted cabling and an air supply line (Figures 5.31 and 5.32) but it was difficult to determine further information from these pieces. Only small portions of air supply line were found at the incident site and it was not possible to draw conclusions about the damage that may have occurred prior to the explosion.

*Figure 5.30* *Inner steel radials used to reinforce tyre located within a 30 m distance from the epicentre of the explosion. Two spools were located within close proximity of one another*

*Figure 5.31* *Fire damaged electrical cabling 132 m east-south-east of the epicentre of the explosion*

Figure 5.32 *Air supply line cable located 61 m from the explosion site in an east-south-east direction. As it is relatively unscathed, it is thought that this was located towards the front of the dolly's draw bar and less subjected to fire*

Figure 5.33 *Tyre fragment that has been affected by fire located 66 m from epicentre in south-south-east direction*

### 5.3.3.5 Spot fires

The hot metal shrapnel from the blast landed on the dry spinifex and started a large number of spot fires. When the first drone was flown by Gold Fields Gruyere JV approximately 2.5 hours after the blast, dozens of spot fires were seen to be still smouldering (Figure 5.34). Vegetation was too sparse for a bush fire to occur.

At 2:28 pm on the day of the explosion, DFES took aerial photos of the blast site from a fixed wing aircraft. These showed that the density of white spots of ash in the bush correlated closely with the presence of metal debris, that is the density of ash spots were nearly all south of the road and the highest density were in the south-east from the crater extending more than 500 m into the bush. The ash spots north of the road were confined to within a small radius less than 60-80 m from the crater and they were comparatively less.

On 26 October 2022 when the Department's investigators, arrived, some ash spots were still smouldering. Later exploration on foot determined that spot fires were found up to approximately 750 m from the crater. The presence of a spot fire provided a good indication for the presence of metal shrapnel.

*Figure 5.34 View following the explosion*

*Note: Spot fires are still burning and most significant distribution of ash is to the south-east of where the vehicle was positioned (Credit: DFES).*

#### 5.3.3.6 Shrapnel and debris conclusions

The most important conclusion from the shrapnel evidence is that there was a loss of containment of ANE due to a hole forming in the aluminium shell.

The presence of heavy pieces of the tanker trailer chassis and dolly located at significant distances from the epicentre of the blast, indicate that the blast occurred from the ground upwards. These pieces cleared trees, and in some circumstances were found embedded within the ground. There was also evidence the largest piece (axle suspension arm) impacted the ground and then bounced 3 m, before it lost momentum by being stopped by a tree.

The spread of the debris located at the incident scene was inconsistent with an explosion within the tanker itself.

These heavy steel pieces could only have achieved positions hundreds of metres on the other side of the road over bushland with an upward-pointing trajectory. Such a trajectory would be considered unlikely if the explosion originated in the elevated aluminium tank, sitting well above the steel chassis.

## 5.4 Size of the explosion

### 5.4.1 Estimation based on observed damage

The size of the explosion can be estimated from the damage done to the surrounding bush. The available literature however is based on estimating the size of the explosion on damage to buildings and structures and not damage to the Australian bush.

The size of the blast was estimated from the outer boundary of damage of snapped tree branches (75-110 mm thick), which occurs at a blast radius of approximately 120 m. A blast pressure of 14 kPa has been allocated as the investigators' best judgement to account for this damage. This overpressure is known to cause significant damage to houses (as found in Table 7, *Hazardous Industry Planning Advisory Paper No. 4 Risk Criteria for Land Use Safety Planning*).

### 5.4.2 Calculation of the size of the explosion

The calculation to determine the size of the explosion is based on the formulae from the Code of practice: *Safe storage of solid ammonium nitrate (4th edition, re-issued)* 2021 and the SAFEX Good Practice Guide: *Storage of Solid Technical Grade Ammonium Nitrate (revision 2)* 2014.

$D = 10.4\ Q^{1/3}$ for a blast overpressure of 14 kPa

Where D is 120 m, the distance in metres of the boundary of tree damage, and Q is the mass of TNT in kg causing the damage.

Solving the equation for Q gives approximately 1.5 tonnes of TNT, with a conservative range of 1-3 tonnes, given the lack of research into this type of damage.

### 5.4.2.1 Support for this estimation of blast pressure

An examination of the literature and other incidents the Department has been involved in, support the estimation that the size of the blast pressure was 1-3 tonnes of TNT equivalent.

Xu et.al, in *Study of crater in the Gobi Desert induced by ground explosion of large amounts of TNT explosive up to 10 tonnes* (2021) studied the craters formed from 1, 3 and 10 tonnes explosions of TNT stacked on the ground in a square arrangement in the Gobi Desert. They obtained craters with typical circular funnel shape. The diameter and depth of the craters were as follows:

| Mass of TNT used | 1 tonne | 3 tonnes | 10 tonnes |
|---|---|---|---|
| Diameter | 4.5 m | 10.0 m | 14.1 m |
| Depth | 0.95 m | 1.5 m | 2.8 m |
| Square footprints of the TNT placement on the ground before the explosion | 2 m x 2 m | 3 m x 3 m | 5 m x 5 m |

*Figure 5.35 Details of the Gobi desert craters and the mass of TNT used*

The ground of the Gobi experiments was fine-grained sand with a large amount of reddish brown gravel. The gravel was 16-64 mm in size although some pieces were greater than 256 mm. The ground was not the same as for the Great Central Road incident (Section 5.1), but is similar in its sand and gravel composition, meaning the blast dimensions of the crater are likely to be similar.

The Great Central Road crater was larger than the Gobi observations, because of the large spread of the ANE pool. This means an estimation of 1-3 tonnes of TNT equivalent is consistent with the sizes of the craters in the Gobi Desert experiments.

The Department has been involved in two other investigations of explosions.

Most recently, the Department undertook an investigation of a vehicle explosion involving 250 kg of high explosives. This was in remote Western Australia, in country very similar to that at the Great Central Road incident. The damage of the blast on the nearby bush was much less pronounced in comparison to the Great Central Road incident and hence the size of the blast at Great Central Road is estimated at much greater than 250 kg TNT equivalent.

The 2002 Western Australian Carmel fireworks explosion (see the Department of Mineral and Petroleum resources *The Carmel Explosions 2002*) was estimated to have involved 230 to 500 kg TNT equivalent based on the damage to surrounding structures. The focus was on property damage and whether the protective distances to houses was sufficient. Specifically, this involved whether the protected works Class B distances were sufficient protection for houses on the border of Class B distances. Homes at these distances experienced broken windows and damage of some roof tiles and displacement of internal plaster wall panels as a direct result from the blast overpressure estimated to be approximately 5.5 kPa. The blast overpressure (estimated at 14 kPa) and the damage at the Great Central Road incident relative to Carmel is significantly greater and the estimated TNT equivalent at the Great Central Road incident is higher than 500 kg TNT equivalent.

### 5.4.3 Conclusion

The 1-3 tonne estimation is a small fraction of the explosive power of 33.85 tonnes of ANE initially present in the tanker trailer. The reasons why the explosion was so small is discussed in detail in Appendix 3.

# 6 The tanker trailer and the driver's qualifications and training

## 6.1 Description of vehicle and tanker design

The vehicle involved in the incident was a double road train measuring 27.5 m in length. The vehicle consisted of a prime mover, tri-axle lead tanker, tri-axle dolly and a tri-axle rear tanker. The tankers were a double cone-shaped tanker or otherwise known as "banana-shaped" tankers, (Figures 6.1. and 6.2).

The tankers were manufactured from aluminium 5083, which is a common aluminium alloy used in cargo tanks and contains 4.0 to 4.9% magnesium. It is highly resistant to attack of corrosion by both seawater and industrial chemicals. It has a melting point of 570 °C, as set out in Thyssenkrupp UK Pty Ltd *Material Data Sheet for Aluminium alloy* (the safety data sheet), and a density of 2.65 g/cc.

Each aluminium tank is mounted on a steel chassis. The aluminium shell was 6 mm thick and the two vertical, circular endplates were 8 mm thick.

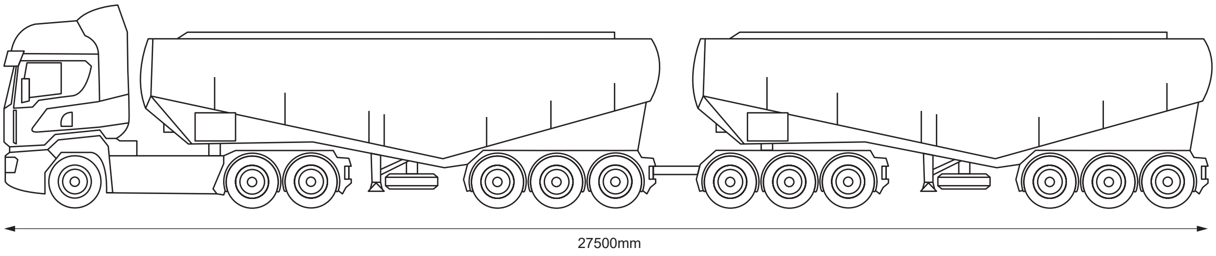


*Figure 6.1 Schematic of road train with two tanker trailers and dolly*

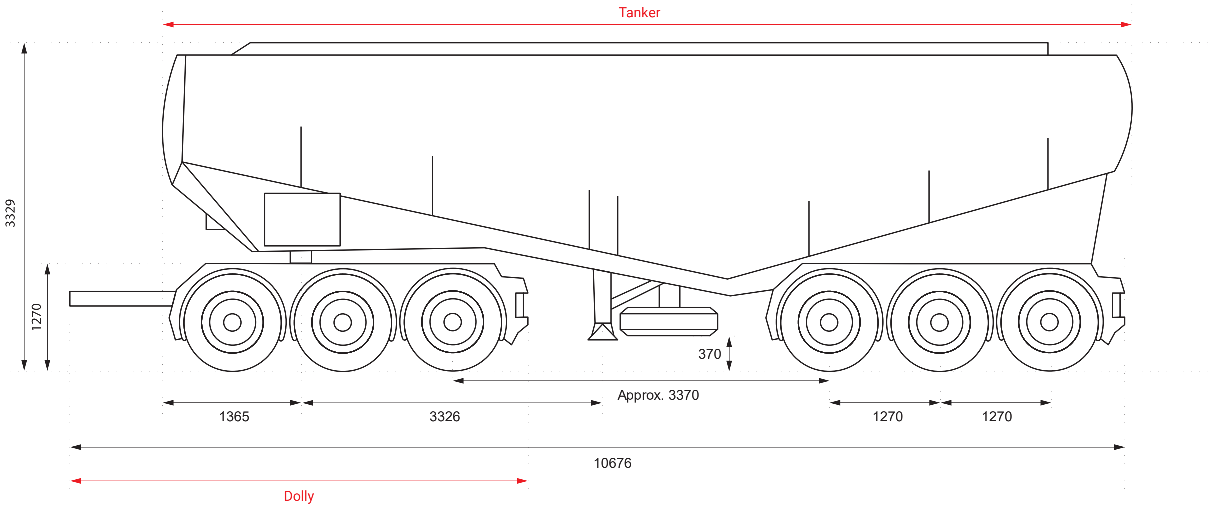


*Figure 6.2 Schematic of tanker trailer and dolly involved in the explosion*

The tanker trailer involved in the explosion was a two-compartment dangerous goods tanker. A forward bulkhead separated a small forward compartment from a large rear compartment. The forward bulkhead contained two large internal valves, one at a high level and one at a low level. These two internal valves are opened for filling the two compartments with product from a single point above the tanker and remained open during transport.

The rear compartment contained the tank's main outlet (discharge point) at the bottom, in the centre of the tanker, and was closed by an internal valve during loading and transport. The main outlet valve feeds the product via a stainless steel discharge pipe into one of two discharge valves – either on the driver's side or the passenger side, depending on the location of the storage tank at the mine site. The tanker was fitted with a pressure/vacuum vent and an emergency vent for each compartment at the top of the tanker.

The two tanker trailers were manufactured in 2019 and specifically approved for the transport of ANE. Approvals from the issuing competent authority (South Australia) were obtained as records. The capacity of the lead tanker was 27 kL and the rear tanker (involved in the explosion) was 29 kL.

The wheel rims of the road train combination were made of an aluminium alloy. The composition and melting point of the alloy is unknown.

The vehicle combination was compliant with the design standards of the ADG Code.

## 6.2 Firefighting capacity

The road train was fitted with two 9 kg dry chemical powder (DCP) fire extinguishers and a 9 L water fire extinguisher. It was also fitted with a 60 L pressurised water tank and hose reel that could be used for fire extinguishing purposes. The pressurised water tank was located on the driver's side (RHS) while the hose was located on the passenger's side of the vehicle.

## 6.3 Maintenance history

The investigation team collected evidence that the tankers were inspected every three weeks and serviced every six weeks by the operator. The tanker trailers had been serviced eight days prior to the incident.

The transport company has two different types of servicing – an 'A' service which is a more general service and a more comprehensive 'B' service. The general service checks on 45 different items and includes greasing various parts of the running gear as well checking to see if there is any 'wobble' or play in the wheels. The more comprehensive service includes the 'A' service as well as changing the wheel bearings, among other things, and is undertaken regularly as a precaution. The wheel bearings on the tanker were last replaced 70,000 km prior to the incident. The Original Equipment Manufacturer (OEM) recommends that the wheel bearings be replaced every 1.2 million km.

The tankers had done two return runs to the mine site since the last service and prior to the incident. It is assessed any issues with the servicing of the tankers would likely have been detected on a prior journey.

For the five months prior to the incident this vehicle combination had been dedicated to making deliveries to Gruyere mine site. The vehicle combination would generally make four return journeys to the mine site every fortnight (travelling approximately 9,500 km per fortnight).

The inside of the tankers are regularly inspected at the loading point prior to filling to ensure that they are in a clean and suitable condition. The tankers had a history of passing checks when being loaded, both internally and externally, and were deemed suitable for loading on 23 October 2022.

## 6.4 Driver qualifications and training

The driver had the valid licences for transporting ANE, was appropriately trained and was experienced at driving heavy haulage vehicles.

The driver had the correct licences for transporting ANE, a SSAN product. He had a current bulk dangerous goods licence for transporting a number of different classes of dangerous goods including Class 5 dangerous goods as well as a current Dangerous Goods Security Clearance (DGSC) card. He was authorised in writing by his employer as a 'secure nominee' – a person authorised under the SSAN Regulations to have unsupervised access to SSAN products. He also held a current heavy vehicle driver's licence to be able to drive articulated heavy haulage vehicles.

The driver was also appropriately trained. Drivers at the company need to undertake and pass nine training modules which includes dangerous goods awareness, the legislation, use of equipment, loading and unloading operations. Modules also include training on the Security Plan, Emergency Response Plans, Emergency Guides and the HB76 book on emergency procedures (all of which are on the company's internal app). The training involves classroom training, practical assessments signed out by one of the company's managers and a written assessment. In addition, the driver needed to be aware of and successfully pass numerous company procedures.

The driver was required to be familiar with all of the companies policies and procedures including the safe transport and security management of dangerous goods, speed and safe driving, work planning, emergency response and connecting/disconnecting trailers. He was up to date with all of the required training and procedures.

The driver was also experienced in driving heavy haulage vehicles. He had been in the industry driving trucks for over 40 years at the time of the incident. Although he had been employed with his current employer for 15 months at the time of the incident, he had worked for another transport company also involved in transporting SSAN products for 7 years, as well as 5 years of mine work, driving trucks.

In his present position, he did 4 return transport runs from Kwinana to Gruyere every 12 days (or fortnight to allow for servicing and breaks). He was driving the involved aluminium tankers for the past five months prior to the incident as the company has retired their fleet of steel tankers. Hence, he was well acquainted with the route, the vehicles and the journey, and was well experienced and trained to undertake this work.

# 7 Relevant accidents in aluminium tankers

It is important to examine past ANE incidents in aluminium tanks/tankers in light of the explosion of the tanker trailer and dolly that occurred in this instance. Such examination provides a better understanding of the circumstances that may be necessary for an explosion to occur and why past transport incidents did not result in an explosion (except for the MPU explosion, which occurred at the blast hole during the manufacture of explosives).

This report will examine the following ANE transport incidents:

1. The Mobile Processing Unit (MPU) explosion at Drevja in Norway on 17 December 2013
2. The Banana tanker trailer fire, Queensland, 5 September 2015
3. The Wowan tanker trailer fire, Queensland, 12 March 2018
4. The Telfer tanker trailer fire, Western Australia, 21 November 2022
5. The New Norcia tanker trailer fire, Western Australia, 3 June 2023

## 7.1 MPU explosion – Drevja, Norway, 2013

An explosion of a MPU took place on a mine site in Norway on 17 December 2013 as detailed in the DSB report. The MPU was loaded with 5,000 kg of ammonium nitrate (AN) and 8,000 kg of ANE in separate 6,600 L aluminium tanks when an electrical fault caused a vehicle fire during the loading of a blast hole. It is not known whether the AN or the ANE or both were responsible for the explosion.

Significantly, prolonged heating of the two aluminium tanks allowed product to escape to the ground. The position of the 900 kg engine block of the MPU some 200 m from the epicentre of the explosion could only be explained by an explosion from the ground upwards and the leaking of product from at least one of the two aluminium tanks.

The fire burned for about 2.5 hours before exploding. The explosion was a detonation involving the energy equivalent to 500-1,000 kg of TNT. This is a low explosive yield and illustrates that most of the approximately 13 metric tonnes of the explosive material either decomposed before the explosion or did not participate in the explosion.

## 7.2 Tanker trailer fire – Banana, Queensland, 2015

On 9 May 2015, ANE was being transported on the Leichardt Highway near the town of Banana in a typical ANE aluminium tanker when a fire started in the 8 tyres of a tandem axle dolly. The driver was unable to extinguish the fire using the extinguishers on board and separated the prime mover and lead tanker to save those vehicles. It took the emergency services more than an hour to attend the scene.

The flame impingement was onto the nose of the barrel tank, the front of the tanker above the steel skid plate. This is a relatively large distance between the fire and the aluminium tank and the tank was partially protected by the steel skid plate significantly reducing the heat flux on the tank. A higher heat flux on the tank occurred during the Wowan (section 7.3) and Great Central Road incidents. In the Wowan and Great Central Road incidents the distance of the aluminium shell to the tyre fire was much shorter and there was no steel skid plate to shield the vulnerable tank surface. The fire was close to the bottom of the tank rather than the nose of the barrel tank. The heat flux was also higher in these incidents compared with the Leichardt Highway incident because the fuel source came from a greater number of burning tyres.

The heat of the fire was sufficient for the product to start localised boiling and decomposition along the side walls of the tanker, but there was no loss of containment. The tanker did not vent correctly and the shell was under pressure to the extent that heat and pressure formed a crack in the shell indicating that the tank was fortunate not to suffer a loss of containment.

Although some of the product boiled and there was product decomposition around the heated walls, the decomposition did not progress into the bulk of the ANE, as there was insufficient heat. The wind conditions may or may not have played a part in further reducing the heat applied to the aluminium shell of the tanker.

## 7.3 Tanker trailer fire – Wowan, Queensland, 2018

The vehicle fire occurred on 12 March 2018 on the Leichardt Highway, 2 km south of Wowan, a small rural town approximately 470 km north-north-west of Brisbane.

The incident occurred on a bitumen surfaced highway and involved a fire on the rear tri-axle group of wheels of the rear ANE tanker trailer, on a B-double combination road train. The tanker trailer was constructed of 8 mm aluminium endplates and a 6 mm aluminium shell (the same as in the Great Central Road incident).

The most likely cause of the fire was excessive friction due to the mechanical failure of a main bearing within the rear tri-axle group. The manufacturer had guaranteed the bearings for 1,000,000 km. It was found that the trailer had travelled approximately 1,042,000 km with the same bearings. The bearings had travelled approximately 48,000 km since the last bearing service where the hub was opened and the bearings were physically inspected, adjusted and greased.

The driver attempted to extinguish the fire using eight 9 kg DCP extinguishers (additional vehicles stopped and assisted) without success. He then disconnected the burning rear trailer from the B-double combination and drove the prime mover and lead trailer to safety without injury or damage.

The aluminium tanker trailer was destroyed by fire and suffered a complete loss of product of approximately 23 tonnes. Most of the rear half of the tank melted or collapsed leaving the front portion of the shell with a gaping hole. Pools of molten aluminium could be seen on and next to the trailer.

Nearly all of the emulsion flowed safely away from the fire into a nearby ditch without decomposition or explosion (Figures 7.1 a and b).

The rear trailer burned for an extended period and involved all 12 tyres from the tri-axle, but not the 2 spare tyres in the centre of the trailer.

After approximately 3.5 hours from the start of the vehicle fire, emergency personnel approached the scene and saw white vapours coming from the ditch that contained the majority of the 23 tonne load of ANE. The bulk of the ANE had not undergone significant decomposition. Flames were still visible inside the remainder of the tank from residues of emulsion.

*Figures 7.1 a and b* *Images of tanker trailer. This shows the flow of bulk unchanged ANE (i.e. had not undergone significant decomposition) that had escaped from the aluminium shell and was away from the tyre fire*

## 7.4 Tanker trailer fire – Telfer, Western Australia, 2022

On 21 November, a triple road train was transporting ANE in aluminium banana tanker trailers to a Telfer mine site. It travelled on an unsealed, poorly maintained road and developed a brake fire in two wheels on the rear tanker. This incident occurred four weeks after the Great Central Road incident and in many respects is similar to it.

The fire occurred due to damage to the air supply line system on a poorly maintained dirt road leading to overheating of dragging brakes. The cause was likely due to a failed hose clamp that allowed the rubber hose carrying the air pressure to separate from its inlet fitting, leading to a loss of air pressure to a number of brakes.

The driver was experienced and noticed a difference in the handling of the combination vehicle as he was ascending a small slope, something that is difficult to notice when driving on a flat road. The driver stopped and found small flames and smoke from the brakes on the rear trailer. There were no pressure or temperature sensors fitted to the vehicle to alert him otherwise.

The driver was able to fully extinguish the fire using two DCP fire extinguishers and half of the capacity of an 80 L water-based foam firefighting system fitted to the vehicle. The system consists of an 80 L water-based foam tank pressurised by the vehicle's air system and a hose long enough to reach all parts of the vehicle combination. A foam agent within an 80 L water reservoir unit was effective in smothering the affected areas and cooling the components to prevent re-ignition. It provides superior performance to water. DCP fire extinguishers are not effective for cooling purposes and cannot prevent re-ignition of flames.

In this incident, the driver was able to detect the fire early due to his training and experience. Having an experienced and a well-trained driver in control of a vehicle with a suitable firefighting system which includes a sufficient supply of a water-based foam and an adequate length of hose, makes it feasible to extinguish a tyre fire before it escalates further.

The investigating transport company highlighted the importance of early detection of elevated wheel hub temperatures in order to prevent a tyre fire and found that while a program of manual temperature measurements with a heat gun is valuable it would not have prevented this particular tyre fire. The company intends to install a constant temperature and pressure wheel hub monitoring system to their fleet of vehicles transporting ANE and AN.

## 7.5 Tanker trailer fire – New Norcia, Western Australia, 2023

On the evening of 3 June 2023 the small monastery town of New Norcia was evacuated. The rear tanker trailer containing 30.97 tonnes of ANE of a 'C-train' (a B-train and a dog trailer) was noticed to be burning, 800 m from the town. The tanker trailers were purpose-built aluminium tankers for the transport of ANE.

The driver first noticed the fire at 8:32 pm while on a right hand bend and saw sparks in his rear vision mirror coming from the passenger-side (LHS) of the rear trailer. He immediately pulled over to the side of the road and noticed a small fire on the two tyres on the centre axle of the tri-axle group of the rear tanker.

He attempted to extinguish the fire using a 9 L foam fire extinguisher. Being unsuccessful, and rather than using the other five 9 L foam extinguishers or the two 80 L pressurised water tanks on the leading trailers, he instead (knowing that the product can explode under certain circumstances) proceeded to disconnect the leading B-double road train from the dog trailer. He drove 700 m forward before raising the alarm and barricading the highway at both ends. The volunteer fire brigade arrived 15 minutes later. The fire was still small and contained to the tyres of the central axle, but they were advised by DFES not to fight the fire and to increase the evacuation distance to approximately 4 km.

The fire was allowed to burn itself out. It spread to the remaining 10 tyres on the rear tri-axle group but did not spread to the dolly tyres. When the fire brigade returned to the scene and safely entered the exclusion zone early the following morning, the fire was still smouldering. Water was applied only to the axles, wheel hubs and remaining tyres to prevent the tanker from cracking.

When the hatch of the tanker was opened in the morning, the ANE within the tanker was approximately 40 °C, slightly discoloured and the viscosity had decreased due to the separation of some of the emulsion into its liquid components. When the product was transferred out of the tanker a thin layer (about 1 mm thickness) of solid AN was observed on the inner surface. The formation of solid AN was limited to where the ANE was in direct contact with the tanker shell and closest to areas that had received prolonged direct heating by the fire (Figure 7.4).

There was no loss of containment in this incident. The tank barrel was buckled at the closest point to one of the tyres (Figure 7.3). The aluminium metal of the tank was starting to show signs of softening and deformation.

The cause of the fire was the failure of a wheel bearing. On the centre axle, LHS of the trailer's tri-axle group.

The vehicle and tanker trailers were regularly serviced, with a C-service having recently been carried out. As part of the service all bearings had been washed and inspected. The bearings and hubs were repacked with grease and new seals were fitted. At the time of servicing, all bearings on the trailer were in good condition.

Following the incident, the condition of the bearings on the RHS of the tanker were inspected and were found to be in good condition.

This was observed by investigators at the transport depot. The vehicle was regularly serviced, with the wheel bearings replaced only two months previously.

It is unclear why the tank barrel did not rupture in this instance. The weather was cool with the temperature dropping below 10 °C that evening with little to no wind. The fire was smaller than the fire at Great Central Road and it did not spread to the tyres on the tandem axle dolly. There were no spare tyres located between the dolly and the tanker trailer. The different weather conditions may explain why the tanker did not rupture in this instance.

*Figure 7.2 Tyre fire on the ANE tanker caused by wheel bearing failure*

*Figure 7.3 Tanker shell starting to buckle caused by the fire*

*Figure 7.4 Inside walls of the tanker after the bulk of the ANE had been transferred. Solid AN formed on the sides where the fire impinged on the tanker. Some discolouration and possible separation of the product has occurred*

# 8 The likely causes of the Great Central Road fire

The cause of the fire cannot be determined with certainty as the tanker was completely destroyed in the explosion.

A fire started in the passenger-side (LHS) rear axle group of the rear tanker as witnessed by the driver.

After discussion with the parties involved, the most likely causes of a wheel fire were:

1. loss of compressed air supply to the brakes causing them to drag, resulting in friction and overheating
2. failure of the wheel bearing assembly
3. auto slack adjustors over-tightening the brakes.

The poor condition of the unsealed, corrugated Great Central Road is identified as a key contributing factor in this incident. In the six month period prior to the incident there was damage sustained to the fleet of vehicles and trailers the transport company was using to service the mine site (these vehicles included a road train combination with tanker trailers and two flat tray tops). The damage incurred while travelling the Great Central Road included:

- broken suspension beam
- broken axle on rear trailer
- new airbag was broken
- crack within chassis from bouncing
- of particular note was an air-line ripped out by a rock, causing a loss of compressed air and resulting in locked brakes.

## 8.1 Overheating brakes

The most likely cause of the wheel fire is a loss of air supply to the brakes. When the brakes are subsequently engaged, it resulted in dragging brakes, causing friction and overheating. The dragging or rubbing of the brake shoes on the wheel drums results in the wheel assembly getting hot, causing the grease to catch alight and cause a tyre fire.

The loss of air pressure activating and locking down the brakes is a built-in safety feature to prevent parked trailers rolling away if air is lost. On sealed roads, brake activation is easily identifiable. On unsealed roads this can go undetected, due to the vehicle's responses to the corrugations and ruts and the dust generated from the road surface. In the hot environment of the Eastern Goldfields where all equipment is already at high temperatures, this is more likely to result in a tyre fire.

The following findings supports this cause:

- discussions and witness statements from the transport company and the driver
- review of previous maintenance and servicing records, showing a long history of equipment failure for tanker trailers using this road
- review of the parties' incident investigation reports
- the condition of the gravel road.

The vehicle was driving on the corrugated road surface for 96 km before the fire was noticed by the driver. It is possible that a rock from the road was thrown up underneath the trailer and punctured the air supply line or that a fastening clamp became loose (as seen in the incident at Telfer).

It is difficult for a driver to detect if there is an air loss because of the size of the air tank reservoir. The indicator on the dashboard of the prime mover may not illuminate if there is a slow air leak. The driver involved in the Great Central Road incident advised that the air pressure sensor did not indicate a change in air pressure.

A driver may find it difficult to detect dragging brakes on corrugated, flat, unsealed roads, because the prime mover is sufficiently powerful to overcome the effect of the dragging or compromised brakes. A driver may also find it difficult to detect a tyre fire early on because of the dust being thrown up by the tyres masking the onset of black smoke.

Another possible cause for the tyre fire is prolonged abrasion of the air supply line, caused by the vibrations of the corrugations. It is possible that the air supply line may have been abraded to the point of air loss. This scenario is less likely, when taking into consideration that the tanker had undergone mechanical servicing eight days earlier, a focus of the servicing was the condition of the air supply lines, and the tanker completed two return journeys without incident since servicing. This means it was unlikely that abrasion was the cause of the incident.

## 8.2 Wheel bearing failure

Another possible cause of the fire is the collapsing of a wheel bearing assembly. The driver did not approach the fire from the passenger-side (LHS) of the vehicle, so he did not identify any visible signs of a wheel bearing assembly failure.

Maintenance records collected from the transport company indicated that the wheel bearing was replaced 5 months earlier and had travelled 70,000 km. The OEM recommends that the bearings be replaced every 1.2 million km so these wheel bearings are considered within the required operating requirements. Regular maintenance on the prime mover and tanker trailers was performed; this included the checking and greasing of the wheel bearings. Part of the servicing included checking for any ‘wobble’ or play in the wheels using a long steel bar and there had been no such sidewards or lateral movement in the wheels. If there had been play or give in the wheels, this could result in friction or sparks where the wheel interacts with the rim and result in a fire.

Further to this, the tanker trailer had completed two return journeys since the last service with no incident and so if there had been an issue with the bearings it is likely that this would have been identified prior to the incident.

Based on the information collected, a collapsed wheel bearing assembly is not considered the cause of the fire.

## 8.3 Automatic slack adjustors overtightening the brakes

Another possible cause of the fire is the automatic slack adjustor overtightening the brakes, causing them to overheat and start a fire.

The tanker trailer was fitted with an electronic braking system (EBS) and hence was legally required to be fitted with automatic slack adjustors. This is to ensure the brakes are effective when being applied (and there is not too much slack in the brakes when being used by the driver).

Various companies have reported that fires have occurred on vehicles fitted with automatic slack adjustors travelling long distances on unsealed gravel roads. The dust from the unsealed road can work its way into the brakes, causing tightening of the brakes which can lead to excessive heat being generated, leading to a fire.

It is thought that this was an unlikely cause of the fire as the tanker trailers had only recently started being driven on unsealed roads. The tanker trailers had been travelling almost exclusively on sealed roads for the past two years and it was not until five months prior to the incident, that they were redirected to transport ANE to the Gruyere mine site. Based on information gathered from the transport company, it is unlikely that this would have been enough time for problems to start occurring in the automatic slack adjustor in the braking system.

The tanker trailer was only serviced eight days prior to the incident and the braking system was checked during the service. Hence, this mechanism is considered an unlikely cause of the fire.

# 9 How the fire led to an explosion

## 9.1 Overview

An examination of the progress of the fire leading to the explosion starts in section 9.2 by presenting the key observations from the driver and the mine ERT. These observations have been used to construct a feasible progression of the fire from the rear axle group tyres to the front axle group (dolly) tyres. Involvement of a second axle group has not occurred in previous fire engulfment incidents with ANE aluminium tankers. It is an important factor of the fire at Great Central Road incident, as it led to the prolonging of the fire for a total of 120 minutes and increased the total tyre fire's heat output.

The following sections discuss the tank failure leading to the loss of containment of the ANE, the ground-based ANE decomposition process to form explosion sensitive molten and gassed-up AN that detonated and the likely initiating event for the explosion.

## 9.2 Progression of the fire as outlined by witnesses

*"The initial fire involved the four rear tyres on the passenger side of the tanker trailer's rear tri-axle group. From there it spread to the rest of the tyres on that side and then to the tyres on the opposite side. This took about 10-15 minutes."*

Driver

*"Some time prior to 11:05 am the fire had spread to the front dolly axle group of 12 tyres. Between approximately 11:05-11:10 am the dolly tyre fire was observed to be fully developed, around 100 minutes after the driver first detected the fire in the rear axle group.*

*We observed a fire from the ground, beneath the tyres."*

Emergency Response team

Based on the observations from the driver and ERT, the fire was transferred from the rear tri-axle group and progressed to the front tri-axle group. It is not clear how this progression occurred. It is likely to have been the oily matrix fuel component of the destroyed emulsion that spilled around all 26 tyres that played a major part in the spread of the fire from the rear axle group to the front axle group. Decomposition of the ANE and the resultant increased explosion risk is discussed at sections 9.4 and 9.5.

Once the driver had left the scene, no observations on the state of the rear axle group of tyres were made, as the ERT only had a front-on view of the vehicle.

It is likely that the front axle group of tyres was still burning after 120 minutes, as smoke and fire continued to be observed by the ERT, right up to the time of the explosion. This is consistent with finding debris of partially burnt rubber, indicating that the tyres were not fully consumed at the time of the explosion.

Figure 9.1 provides the important observations of witnesses in a timeline of events.

At 9:31 am

- Driver notices black smoke through the dust on rear axle group of the rear trailer
- Driver parks the double road train about 3 m from gully on the side of the road
- 4 tyres on the tanker trailer's rear tri-axle group, located on the passenger's side of the tanker, are alight.

At 9:33 am

- Driver attempted to extinguish the fire with on-board fire extinguishers
- Fire has progressed to all 6 tyres on passengers side of rear tri-axle group.

At 9:45 am

- Air bag suspension bursts
- Driver disconnects dolly from the front trailer
- Fire has progressed to the tyres on the driver's side. The fire now involves all 12 tyres on rear tri-axle group.

At 9:50 am

- Driver leaves the incident scene
- Flames were approximately 600 – 900 mm high and 450 mm above the rubber mudguards.

At approximately 10:05 am

- Driver noticed white smoke mingled with the black smoke from a distance of 3 km (outside barricaded area).

At 10:50 am

- ERT arrive at barricaded area.

At approximately 11:05 am – 11:10 am

- Fire tender approached the incident scene to warn and usher a motor cyclist and a vehicle arriving from the west out of the barricaded area
- ERT drove to within 1300 m of the fire, having had to pass the bend in the road
- Using binoculars they observed high flames coming from the burning tyres of the front tri-axle group of the dolly. They also saw fire coming from the ground originating from underneath the dolly and near the trailer
- Observed plumes of smoke (approximately 20 m in height) constantly changing colour from black to grey to white depending on the wind.

Between approximately 11:15 am – 11:33 am

- Observed the smoke plume rising and the fire continuing to burn from the barricaded area, approximately 3 km away.

At 11:33 am

- Observed the explosion with a large fireball extending deep into the bush and smoke plume approximately 1 km high
- Took photos of the explosion
- Observed small fires break out in the surrounding bushland.

*Figure 9.1 Timeline of events*

## 9.3 Loss of containment of ammonium nitrate emulsion due to tank failure

### 9.3.1 Evidence for a loss of containment of ammonium nitrate emulsion

There is sufficient evidence to support the finding that there was a loss of containment of ANE from the tanker. This evidence includes:

- a large quantity of molten solidified aluminium debris was found within and near the crater, while other pieces were found several hundred metres from the epicentre (Section 5.3.3.2). The source of the molten aluminium is from the tank shell or the wheel trims or both.
- large heavy steel pieces were found embedded within the ground. These were found at significant distances from the epicentre of the explosion behind undamaged bushland and demonstrate an upwards trajectory of the steel pieces. This supports an explosion from the ground propelling the steel chassis upwards, rather than an explosion from height inside the aluminium tank.
- the large surface area and the position of the crater aligns with the position of ANE that spilled from the tanker after a loss of containment and was trapped in position by the topography of the road.
- observations of white smoke were made at different times throughout the course of the fire by the driver and the ERT, which indicates the presence of decomposing AN.

The driver observed white smoke at about 30 minutes after he first noticed the fire, an indication of both the decomposition of AN and a loss of containment. Appendix 1.3 provides a detailed explanation of how the white fumes are generated from the decomposition of AN.

The driver left the scene after the rear tri-axle group fire was fully developed. He observed the white smoke 10-15 minutes after this. This duration is consistent with the Kuosanen fire tests, when the appearance of white smoke signalled a loss of containment 5 minutes (2002 tests) and 10 minutes (2007 test) after the fire had fully developed (Kalström, H and Nilimaa F [2002] and Kalström, H et.al, [2007]).

The loss of containment of ANE in aluminium tankers when subject to fire is not new. Loss of containment from aluminium tanks was observed in the Kuosanen large-scale fire tests (Appendix 2) and the Wowan ANE tanker fire incident in Queensland on 12 March 2018 described at section 7.3.

### 9.3.2 The circumstances leading to the loss of containment of ammonium nitrate emulsion

There are several circumstances that led to the loss of containment of ANE from the tanker. This includes:

- An intense fire in the rear tri-axle group. The driver observed all tyres on the rear tri-axle group were alight when the driver disconnected the dolly and tanker trailer at around 9:50 am, with the flames projecting about 450 mm above the mudguards.
- The rubber mudguards were likely to have been consumed early adding to the development of the fire and the impact of the fire on the tanker.
- The bottom of the tanker shell was very close to the burning front tyres of the rear tri-axle group (370 mm). When the tyres and the air bag suspension burst, the proximity of the flames to the tanker shell would have decreased further.
- The melting point of the aluminium tanker shell was 570 °C and this is lower than the temperatures the tyre fire would have reached (in the order of 1,100 °C as determined in the DSB report). Prolonged flame impingement on the tanker shell would have resulted in a hole forming in the tanker and a loss of containment of the ANE.
- The tanker's "banana" design acted as a funnel, draining most of the tanker's ANE contents from a hole that developed near the bottom of the aluminium ANE tank onto the fire.

The fire continued to burn leading up to the explosion, as observed by the ERT. In the normal course of events, a tyre fire, without other fuel sources, would be expected to have largely burned out after 60 minutes, according to data from actual incidents and various full-scale tests (Hansen 1995). The Kuosanen 2007 (Kalström, H et.al,, 2007) fire test reports that the visible flames of the tyre fire had diminished after 54 minutes, further supporting the 60 minute duration observed at Great Central Road. Therefore it is likely that the tyre fire of the rear axle group of the tanker trailer had substantially diminished after 60 minutes. Most likely, the front dolly axle group of tyres and the fuel from the destroyed emulsion continued as the only source of heat input until the explosion.

The driver did not observe the mudguards alight, but it is reasonable to think the mudguards were alight soon after the driver left the incident scene, because of the height of the flames when he left the scene. Rubber mudguards lack the heat shielding properties of stainless steel and do not offer adequate fire protection to a tanker shell. With the mudguards burned away, the flames of the closest burning tyre would have been higher and closer to the tank, a distance of only 370 mm.

The close proximity of flames on the tyres to the tank melted a hole in the aluminium shell near the bottom of the tank, resulting in a loss of containment of a significant quantity of ANE.

The two internal valves of the bulkhead, separating the two compartments of tank, are kept open at all times during the loading, unloading and transport of the tanker (section 6.1). It is expected that most of the viscous ANE was able to drain out onto the ground below because of the 'banana' design. This would have resulted in most of the 33.85 T or 25.5 kL of ANE spilling onto the ground in its original emulsion form, as yet unaffected by the fire and close to its ambient temperature (see section 9.3.3 regarding the low thermal conductivity of ANE).

It is likely the ANE would have spilled mainly north on the passenger-side of the tanker down the slight slope on the road towards the road gully (Figure 9.2). It also would have flowed beneath the tanker and around both axle groups of tyres because of the large volume of ANE.

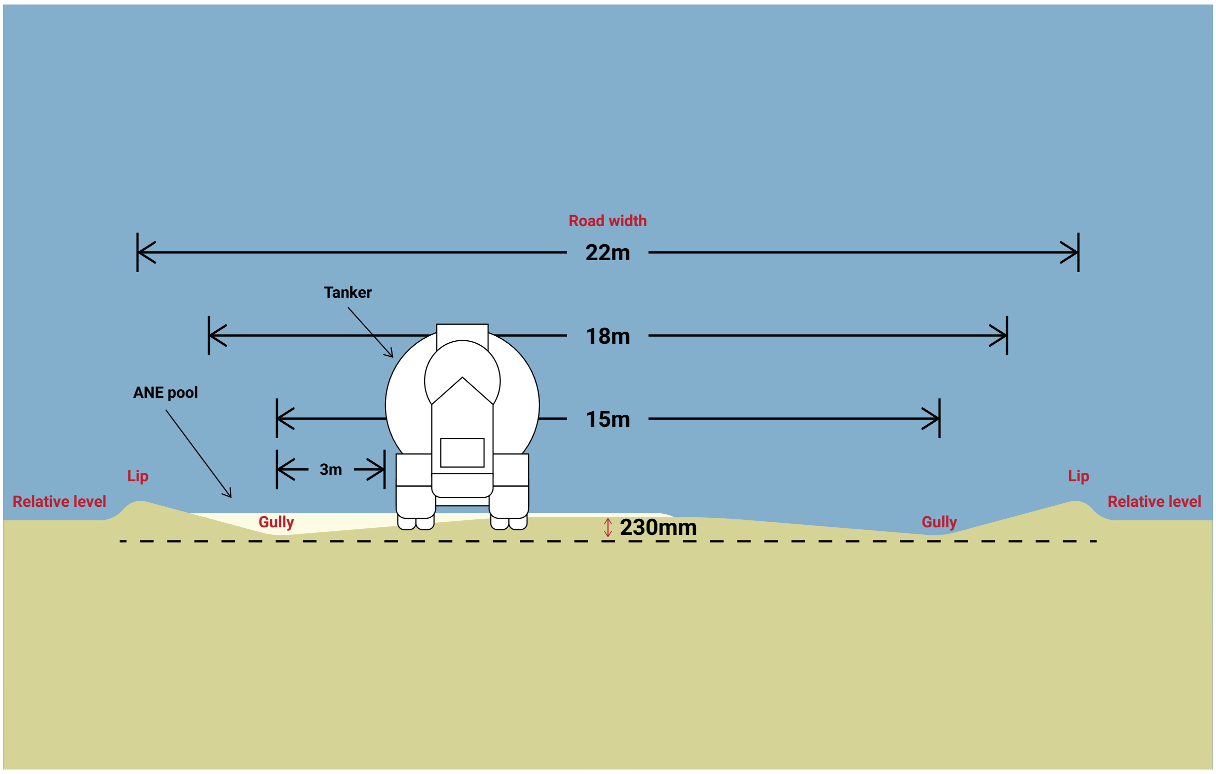


*Figure 9.2* *Schematic of the road and approximate location of the tanker trailer and dolly. The ANE pooled into a gully on the passenger-side and beneath the tanker trailer after a loss of containment occurred*

### 9.3.3 The significance of the thermal properties of ammonium nitrate emulsion

The internal tanker shell was not effectively cooled by the ANE due to the thermal and physical characteristics of ANE, creating a localised hot spot where the flames impinged on the shell wall. It is likely that the tanker shell failed as a result of this, melting and forming a hole in close proximity to the flames.

Large aluminium tanks containing ANE melt at a localised region due in part to the low thermal conductivity of the emulsion matrix. This creates a localised hot spot as the heat is supplied at a higher rate than the ANE can draw it away.

In the Great Central Road incident, the aluminium surface of the tanker, heated directly by the tyre fire, received little internal cooling from the ANE and the aluminium reached its melting point relatively quickly after the driver departed the scene.

The low thermal conductivity of ANE has been explained in a UN paper from the Institute of Makers of Explosives (IME) *Recommendations on Test Series 8: Applicability of Test Series 8 (d)* 2021 (the UN Test Series Recommendations). The low thermal conductivity of the oily emulsion matrix limits the internal cooling of the aluminium tank through a lack of convection currents, which, with other liquids, would normally assist with cooling.

The melting point of the aluminium magnesium alloy involved was approximately 570 °C and the melting point of the carbon steel chassis was 1,425-1,540° C (thyssenkrupp n.d.). Tyre fire temperatures are approximately 1,100 °C, as reported in Kuosanen 2007.

Another consequence of the low thermal conductivity is that any decomposition of the emulsion within the tanker would be confined to the layer of emulsion in contact with the hot aluminium shell. The temperature of the ANE further from the fire's location on the tank shell, would have a lower temperature and not decompose.

In this instance it is possible that some limited ANE decomposition had occurred, but was likely localised to the area close to the aluminium/ANE interface where the flames impinged on the tanker shell. The IME paper includes a report that a 2018 US transport fire in a steel ANE tanker showed that a thin dry crust of mainly AN had developed inside the steel tank wall. The extent of such decomposition within the tanker that would have occurred at Great Central Road would be less, because of the melting of the aluminium tanker shell and the subsequent loss of containment soon after the fire was fully developed.

## 9.4 Decomposition of the ground-based ammonium nitrate emulsion

There are several factors to support the finding that the pooled ANE on the ground decomposed to form molten AN, which made it possible for an explosion to be initiated.

Once on the ground, the ANE closest to the burning tyres was exposed to fire, while the rest of the product experienced radiant heat input. The topography of the road (see figure 9.2) trapped the ANE next to and under the burning trailer and dolly and exposed it to a sustained application of heat (from the 26 tyres).

ANE contacting the burning tyres would experience the highest temperatures and would produce white fumes as observed by the driver and the ERT, characteristic of AN decomposition at temperatures of 240 °C to 292 °C. The white fumes consist of subliming, finely-divided AN crystals and condensing nitric acid vapour, as explained by Reaction 4 of Appendix 1.3. White fumes occurred within 30 minutes of the driver's first observation of fire.

Except for the decomposition of the ANE in immediate contact with the high-temperature burning tyres, the bulk of the ANE will experience more gradual temperature rises and will go through decomposition reactions with the increase in temperature. Initially, the decomposition will be slow while the emulsion structure is breaking down, because the low thermal conductivity of the emulsion prevents mass circulation by convection currents. This effect, plus the need to boil off the water resulting in a concentrated product, contributes to explain why the explosion did not occur until two hours after the initial fire was observed.

Appendix 1.2 reviews the most relevant literature on the reactions and explosion risk of ANE that is released into an open fire. Kennedy's (2003) analysis of the behaviour of ANE in the Modified Vented Pipe Test (MVPT) allows for predictions of how ANE may react in the scenario where it is exposed to an open flame, such as in this incident at Great Central Road. See Appendix 1.2 for greater detail of the various decomposition reactions.

With the application of sufficient heat, the emulsion structure starts to break down slowly at approximately 140 °C into a concentrated high-density aqueous solution of AN containing dispersed droplets of low-density combustible liquid. At the same time, the water content is boiling off, causing turbulence, which keeps the combustible liquid droplets dispersed.

The resulting liquid mixture will undergo convective mixing and distribute the heat somewhat more evenly among the decomposing mixture. This encourages the breakdown of the emulsion into two immiscible liquids.

The droplets of combustible liquid consist of a larger portion of mineral oil with an initial flashpoint of less than 100 °C and a smaller portion of emulsifying agent of proprietary composition. The newly formed mineral oil vapour above the heterogeneous mixture will ignite on flame contact with the burning tyres providing additional heat, increasing the temperature of the mixture and speeding up the boil-off of the water.

When the boiling point of the water reaches 170 °C, the AN concentration is 95%. At this stage, boiling ceases as there is little water left alongside the molten AN. The system will settle into two layers with the heavy molten AN at the bottom and the lighter burning organic oily component on top.

When the temperature increases above 210 °C, the molten AN starts to decompose and be consumed, producing various gaseous products explained in more detail in Appendix 1.2. At this stage no or very little combustible liquid is left.

King et.al, (1978) studied the explosion sensitivity of the AN melt and showed that it rises from 220 °C to a maximum at 270 °C, because of the increasing degree of gassing and lowering of the density. In this state it could be classified as a 'goods too dangerous to transport'.

This now highly sensitised product can be detonated with a No. 6 detonator of 0.25 g net explosive quantity (NEQ). By comparison, to detonate solid AN prill it would take approximately 100,000 times the NEQ.

Potentially all of the AN can be consumed by gas producing reactions until there is none left, a common outcome of a fire involving molten AN.

However, molten, sensitised AN is unpredictable. Conditions involving one or more of the following circumstances can lead to an explosion of the molten AN: confinement, contamination or shock initiation, as discussed in section 9.6.

As the heat transfer within the pooled liquid is not applied evenly, it is likely that at the time of the explosion there was a mixture of sensitised AN as well as some unsensitised AN and intact ANE present. The latter two components would be expected at the margins of the original ANE spread, furthest from the burning tyres.

From the time the white fumes first signalled a loss of containment (30 minutes after detection of the fire) to the time of the explosion (approximately 90 minutes later), there was ample time for a significant portion of the AN to be reduced to gaseous products and hence decreasing the power of the subsequent AN explosion. Other factors decrease the power of the explosion as explained in Appendix 3.

## 9.5 Circumstances that increased the explosion risk

The benign outcomes of the Kuosanen fire tests have been important in supporting the general view that ANE transport in aluminium tankers is safer than in steel tankers. It is instructive however to contrast the Kuosanen fire test conditions with the circumstances of the Great Central Road incident in order to better understand why an explosion occurred. This comparison can be found at Appendix 2.2.

This section explores the circumstances that aligned in the Great Central Road incident to prolong and intensify the decomposition of the ANE by either increasing the heat input into, or decreasing the heat loss from, the decomposing mixture. This increased rate of decomposition of the ANE is thought to have indirectly increased the explosion risk by promoting the formation of sensitised molten AN.

The following is a list of circumstances that increased the rate of decomposition leading to the increased risk of an explosion:

- a prolonged and intense fire involving 26 tyres
- the low ground clearance for the tanker, which trapped heat between the ground and the tanker shell and the central location of the spare tyres, which may have aided in the spread of the fire from rear tri-axle to the front tri-axle group
- the entrapment of a significant amount of ANE, around and close to the burning tyres
- the presence of approximately 2,400 kg of fuel from the organic components derived from the ANE, which is of a large scale
- the weather conditions including low-humidity, warm ambient temperature and low wind-speed (Appendix 6).

### 9.5.1 A prolonged and intense tyre fire

It was unusual to have had both tri-axle groups of 24 tyres plus the two spare tyres involved in a vehicle fire. From the available literature, fire engulfment of ANE tankers involved only one of the axle groups of burning tyres and provided a significantly smaller amount of fuel energy than released in the Great Central Road incident.

Tyre fires burn for approximately 60 minutes as detailed in Kuosanen. Given the fire was observed to continue for two hours until the explosion, it is likely that the front dolly group of tyres started burning after the rear tri-axle group fire had diminished. This resulted in a prolonged fire application to the product, which would have led to significant decomposition of the ANE.

### 9.5.2 The significance of a low ground clearance and the location of the spare tyres

The bottom of the tanker is 800 mm above the ground. The driver observed the tanker's airbag suspension had burst early in the development of the fire and the tanker had dropped 100 mm. As the tyres become deflated or burst as the fire progressed, the tanker would have dropped another 250 mm.

This resulted in the ground clearance from the bottom of the tank reducing significantly from 800 mm to 450 mm. This would have created a more confined space that allowed better retention of heat, as it would have radiated back and forth between the hot aluminium shell, the steel chassis and the burning ANE on the ground.

The two horizontal spare tyres on the tanker originally had a ground clearance of 370 mm (Figures 9.3 and 6.2). The collapse of the airbag suspension and tyres would have reduced the ground clearance to 20 mm. The flames from the burning combustible liquid content of the ANE would have been in direct contact with the tyres, causing them and the tyres of the front tri-axle group to ignite. The burning combustible liquid is considered the most plausible mechanism for the transfer of fire to occur to the front axle group of tyres.

Another possible cause of the fire spreading from the rear to the front axle group of tyres is that the centrally located spare tyres acted as a fire bridge to set the front axle group of tyres alight (Figures 9.3 and 6.2).

The distance between the spare tyre and the nearest rear tri-axle is approximately one third of the distance between the two tri-axle groups, meaning it is more likely that the flames could have spread via the spare tyres rather than from tri-axle to tri-axle.

It is not known whether the tyres in the front axle group of the dolly were ignited by flames from the central spare tyres, or by flames from the ground-based combustible liquid content of the ANE, or both. What is known is that they were alight when the ERT observed them between 11:05-11:10 am and it is highly likely they were the tyres responsible for the majority of the smoke plume prior to the explosion at 11:33 am.

*Figure 9.3 Image of lead tanker trailer that arrived at Gruyere mine*

*Note: The proximity of the spare tyre to the rear tyres, as well as proximity to the ground.*

### 9.5.3 The flow of the ammonium nitrate emulsion close to and around the burning tyres

It is highly probable that the spilled ANE from the failed tanker trailer was constrained by the gravel road's topography as described in Section 5.1. The road contours trapped the ANE and forced it to decompose around and close to the burning tyres, rather than flowing off the road and away from the fire, as in other incidents. The road topography and the location of the tanker determined the distribution of the ANE to be under the tanker and near the tanker on the passenger-side.

### 9.5.4 The significance of scale

The large quantity of pooled ANE is expected to intensify the fire significantly, due to its organic carbon content. This is likely to have played an important role in increasing the rate of decomposition of ANE relative to the smaller scale experiments of Kuosanen.

Past experience of burning waste explosives has demonstrated that accidental explosions can occur. To reduce this explosion risk, the mass of waste explosives is decreased and the resultant fire temperatures are reduced resulting in less potential for an explosion. The same argument could be made here, that had there been less ANE involved in the fire, then it would have been less likely to result in an explosion.

### 9.5.5 The weather

The warm, relatively calm and dry weather conditions during the Great Central Road incident were likely to be a factor in minimising heat losses to the environment from the decomposing mixture, compared to the cold, windier and high relative humidity conditions for the Kuosanen fire tests in the Swedish winter (see Appendix 6).

## 9.6 Potential explosion mechanisms

### 9.6.1 Introduction

The exact initiation mechanism of the detonation is not known. In this section, the possible initiation mechanisms will be discussed.

Given the lengthy time of decomposition, it is likely that most of the ANE was destroyed and existed as molten, gassed-up and therefore sensitised AN. It would only require an initiation in a small part of the sensitised AN to set off a detonation involving the remainder of the molten AN.

K. D. Shah (2018) lists four main mechanisms for initiating an explosion or detonation, based on the known causes of accidents with AN and their investigations:

- shock initiation by a high velocity projectile of molten gas-sensitised AN
- deflagration-to-detonation[1] transition (DDT) of a gas-sensitised, contaminated molten AN (US Bureau of Mines, 1966)
- shock initiation by another explosive
- heating under severe confinement.

Of the four mechanisms, the most likely initiating event in the Great Central Road incident may have been shock by a high velocity projectile impacting molten, gas-sensitised AN, discussed at section 9.6.2. The next most likely mechanism could involve a DDT of the sensitised AN melt discussed at section 9.6.3.

Investigations carried out by the US Bureau of Mines (1953) have shown that it is possible to trigger a detonation by heat and confinement if the AN melt is subjected to at least a few hundred psi. A pressure explosion due to the decomposition gases rupturing the vessel containing the molten AN can also occur and is more common than a detonation.

Lastly, a shock initiation by another explosive cannot be discounted. A highly reactive, unidentified substance may have reacted with a small part of the molten AN to generate a heat-sensitive explosive. An unidentified explosive could have detonated under the high temperatures around the wheel hubs and acted as a detonator triggering a detonation in the rest of the molten AN mixture.

For example, the electrical copper wires of the trailer may have reacted with molten AN to form heat-sensitive tetra-amine copper nitrate or TACN, which may have undergone a DDT and acted as the detonator for the sensitised molten AN. Some steel components may have been galvanised containing zinc, which is also incompatible with AN and may have generated an initiating explosive substance.

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[1] *Deflagration is a rapid oxidation process whereas in a detonation a supersonic shock wave is generated. During a deflagration, the chemical reaction zone travels from one particle of the substance to another by thermal conduction. In detonation the propagation is by a hydrodynamic shock.*

### 9.6.2 Possible means of shock initiation by an energetic projectile

Shock is a known mechanism for initiating detonations in gassed-up, molten AN.

The following are possible initiating shock events that may have triggered the explosion at Great Central Road.

- A tyre explosion either in direct contact or very close to the decomposing AN may have provided the initiating energy.
- A heavy piece of steel falling from height as the aluminium tanker was slowly melting at its base may have provided the initiating energy. Potential tanker pieces include the external emergency vent, manhole cover, or the high-level internal valve in the forward bulkhead which separates the two compartments. Another possibility is the total collapse of the aluminium shell onto the ground-based ANE.
- A sealed stainless steel discharge pipe was fitted at the base of the tanker which may have contained approximately 20 kg of ANE residue. The discharge pipe was located at the bottom of the tanker and close to the ground (Figures 6.2 and 9.3). The steel pipe was sealed with stainless steel valves. Stainless steel has a melting point of around 1,400-1,450 °C, much higher than the temperature of the fire. The product inside the pipe would decompose producing either a pressure explosion, depending on the bursting pressure of the pipe, or a detonation if the bursting pressure was higher than the minimum bursting pressure of the ANE. The impact of the shrapnel from the pipe hitting the molten AN could have caused the explosion.
- The driver used three fire extinguishers and placed them on the ground on the driver side, slightly underneath the trailer. Fire extinguishers are pressure vessels that can also pressure explode when heated.

### 9.6.3 Possible DDT from organic contaminants

A fuel-contaminated molten and gas-sensitised AN may be able to undergo a DDT. It is possible that enough organic components escaped the combustion process and were able to contaminate the molten AN in quantities greater than 0.2% of organic carbon content.

There are several likely sources for organic carbon to further sensitise the molten AN. This includes vehicle components such as rubber from burning tyre or mudguards, other combustible debris on the road surface, the fuel component from the ANE and partially burned carbon soot. For example the mixture of molten rubber (from the tyres) and molten sensitised AN in direct contact with the high temperatures around the steel wheel hubs may be enough to undergo a DDT.

It is possible that the sensitised, carbon-contaminated molten AN transitioned from deflagration to detonation without an additional shock initiation or confinement, but the probability of a detonation would increase if an additional shock event or confinement event had occurred.

### 9.6.4 Initiating events that have been discounted

It is not possible to identify a definite cause of the explosion for the Great Central Road tanker incident, which is not uncommon in AN explosions. The following causes however can be discounted.

- A pressure explosion, as a result of blocked tanker vents. There is sufficient evidence to discount this mechanism because there was a loss of containment of the ANE within ten minutes of the tyre fire being fully developed. A hole would have formed in the aluminium tanker before any significant pressure built up due to the decomposition of the ANE inside the tanker.
- An explosion from a sensitised ANE batch. There is no evidence to support this argument. Laboratory testing conducted on a sample from the lead tanker and a batch retained by the manufacturer found the results to be within the manufacturer's specification regarding all chemical and physical properties, see Appendix 4.

# 10 Emergency response considerations

In light of the Great Central Road incident it is timely to examine whether any changes to emergency responses should be considered.

## 10.1 A new awareness of the explosion risk of ammonium nitrate emulsion in a tanker fire

The explosion risk of transporting ANEs in tankers has not changed. The risk remains lower than the explosion risk of transporting AN, and much lower compared to ammonium nitrate fuel oil (ANFO), or explosives such as Division 1.1D or 1.5D.

The Great Central Road incident has raised a new awareness of ANEs potential to detonate after a loss of containment during a vehicle fire, from an aluminium tanker in certain circumstances. The detonation arises from the molten AN derived from the decomposition of ground-based ANE. The explosion from ground-based ANE that had decomposed to AN is a new credible scenario.

Pressure explosions in steel tankers in the order of 2-6 bar were previously the only potential scenario for an explosion involving ANE tankers. Steel tankers undergoing a pressure explosion could also result in a loss of containment and pose a detonation risk similar to the Great Central Road incident.

## 10.2 The choice between steel and aluminium ammonium nitrate emulsion tankers

Despite the Great Central Road incident, aluminium tankers continue to retain a distinct safety advantage over steel tankers due to the lack of confinement in contrast to steel. Steel tankers may explode from a build-up of pressure when the ANE in a tanker or portable tank is subjected to fire, as demonstrated at Kuosanen in 2007 and confirmed by a number of IME United Nations (UN) discussion papers.

Aluminium tankers are favoured within Australia as they are lighter and hence more cost-effective to run due to larger payloads[2]. There are also cost benefits in manufacturing them from aluminium rather than stainless steel. Tankers made from mild steel require protection from corrosion with a liner that requires ongoing maintenance and inspection.

Solid aluminium metal is not flammable unlike the known flammability of aluminium powder. A significant number of experiments have been conducted to eliminate molten aluminium as a combustible (reaction with oxygen) or reactive component (reaction with molten AN). The instant formation of an inert aluminium oxide layer over the molten aluminium accounts for this lack of reactivity (Due-Hansen & Johannessen [2015] and Alcan Marine [2021]).

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[2] *The part of a vehicle's load from which revenue is derived e.g. the volume of ANE.*

## 10.3 What we know about steel ammonium nitrate emulsion road tankers in a fire

In Australia, there have been few incidents involving ANE steel tankers in fully developed vehicle fires. By contrast, since 2014 Australia has witnessed 4 incidents in which aluminium tankers were involved in fully developed tyre fires – 2 incidents resulted in a loss of containment of ANE and 2 incidents did not. There are also three Scandinavian large-scale fire tests that all resulted in a loss of containment. The limited information from incidents involving the fire engulfment of steel tankers has contributed to the uncertainty over the level of risk of a pressure explosion. However some research has been undertaken to attempt to better understand the risk of pressure explosions from steel tankers and portable steel tanks.

In June of 2020, as demonstrated in the UN Test Series Recommendations, the IME explained to the UN committee of experts on the transport of dangerous goods that any potential explosion inside a steel tanker would be a low-order pressure explosion equal to the bursting pressure of the steel tanker and not a more violent deflagration or detonation. The IME concluded that due to the poor thermal conductivity of ANE, the pressure explosion would only involve a small mass of decomposed material near the hot tank wall, and the major product at the time of the pressure explosion would be unchanged ANE in its original form. They explained that the ANE has a Minimum Burning Pressure (MBP) that is more than an order of magnitude higher than the bursting pressure of the steel tank and hence ANE would not participate in the explosion.

A single large-scale fire test in Kuosanen (2007) used a portable steel tank (an isotainer), with a 25 mm diameter pressure relief valve. It resulted in a 10 bar pressure explosion, which is consistent with the advice from the IME. The pressure explosion came after only three minutes of heating in a fully developed fire. It took 5 minutes to fully develop the fire using 400 L of diesel fuel and 8 tyres within a metal bund. The pressure tore the top of the tank open and projected two fragments in opposite directions: 116 kg piece was found at 92 m, and a 43 kg piece was found at 76 m. This experiment highlights the unsuitability of current UN requirements for the transport of ANE in steel portable tanks. The venting capacity is very small and the Special Tank Provision TP32 allows the discharge pressure to be as high as 2.65 bar instead of discharging close to atmospheric pressure at the beginning of the decomposition process.

The behaviour of Australian steel ANE road tanker in a tyre fire is likely to be different to the Kuosanen experiment. The bursting pressure of a steel road tankers is 2-6 bar and lower than for a portable tank, hence one would expect a less violent pressure explosion. The time it would take to get to a pressure explosion would likely be longer than in the 2007 Kuosanen experiment, involving a more gradual involvement of the tyres without a diesel accelerant.

In order to prevent or reduce the risk of pressure explosion, the most recent edition of AS 2809.4 has introduced a large venting capacity with venting starting at atmospheric pressure among other design requirements for ANE tankers. AS 2809.4 requires a large emergency vent area of 196,250 mm² for every 15,000 L of tank capacity, which is equivalent to one 500 mm diameter opening per 15,000 L tank capacity. This can be achieved with loose-fitting manholes or nylon securing bolts that melt at a low temperature. These requirements will be mandatory from 1 April 2024 for the construction of all new ANE tankers, because of the mandating of edition 7.8 of the ADG Code on that date.

A large venting capacity is likely to significantly reduce or prevent the potential for a pressure explosion to occur in steel tankers. At the very least it will increase the time when a pressure explosion will occur. To resolve the questions of whether or when a pressure explosion occurs in a tyre fire it would be desirable to conduct a large scale fire test with a steel tanker fitted out with the venting requirements of AS 2809.4.

## 10.4 Emergency response to fires involving ammonium nitrate emulsion tankers

The fighting of a fire involving a road tanker carrying ANE should only be attempted while the fire is controllable and has not engulfed the tank that contains the ANE.

It is important that fires are quickly extinguished while they are small and controllable to reduce the impact that fires have on the ANE load. The potential outcome or consequences of an incident can be significantly different depending on the early actions by the driver. Once fire engulfment of the tank occurs, the fire is beyond the driver's capacity to fight and involves potentially dangerous product decomposition.

In the Great Central Road incident, the number and type of portable fire extinguishers fitted to the vehicle was inappropriate for the type and size of fire that occurred despite being compliant with legislative requirements. The remoteness of the incident meant that there was limited potential for fire services or other assistance to be provided in a reasonable time to extinguish the fire. Sufficient and appropriate pressurised foam or water based firefighting systems are required to be fitted to vehicles to better equip drivers to extinguish ANE tanker fires (Chapter 11). These systems should be used as long as it takes to extinguish the fire and sufficiently cool any tyres involved so as to prevent re-ignition, unless the driver is endangered by the fire and/or the likelihood of success becomes low. The driver's safety comes first at all times.

With aluminium tankers, the driver can have confidence that no explosion will occur when fighting fires in the early stage of the fire before a loss of containment.

While early attention to a tyre fire is a priority, consideration should also be given to when to alert emergency services.

The driver must immediately evacuate with the prime mover and any intact tankers to a safe distance:

- when the fire engulfs the tank
- firefighting is unsuccessful
- a loss of containment is either imminent or has occurred.

The driver needs to establish an exclusion zone to limit traffic access to the incident scene, with assistance of emergency services or others if available. In remote areas, no further firefighting should be conducted until the fire has burned itself out.

With the right firefighting system and early detection of the fire, the likelihood of a driver being able to extinguish a tyre or vehicle fire is greatly improved. The fire will still be small and much easier to manage. This is likely to prevent the loss of containment and the subsequent decomposition of the product leading to an explosion. Companies should consider re-evaluating their emergency response policies if drivers are not currently trained to monitor and respond to tyre fires. The risk of fire not being fought in a timely way in a densely populated area could be catastrophic.

An optimal driver response requires practical training on portable fire extinguishers and firefighting systems. In addition to this, theory based training on the explosion risks of ANE is required to inform and implement an appropriate emergency response, for example alerting emergency services, evacuating to a safe distance of 1.6 km from the incident scene and, if possible, preventing other traffic from entering the exclusion zone.

The current 1.6 km evacuation distances recommended by the *Australian & New Zealand Emergency Response Guide Book* for vehicle fires involving AN is recommended for all ANE tankers regardless of construction. *Emergency Guide No.140* should be reviewed to advise that the 1.6 km evacuation distance for AN vehicle fires should also apply to ANE tankers (UN 3375) and for hot concentrated AN solutions (also known as ANSOL) (UN 2426).

Where people and property are at risk the emergency services should consider applying water or foam to extinguish the fire remotely (by using unmanned water monitors), ensuring firefighters are in a location that offers protection from an explosion. Cooling the tanker with water will greatly assist in stopping dangerous decomposition of ANE inside the tanker. The advent of new technology, such as drones with the capacity to use thermal imaging cameras, may be of assistance in determining the temperatures of the ANE within the tanker, providing insight to the possible state of decomposition.

Undecomposed ANE in its original form poses no risk of an explosion once it is located away from the fire because it is no longer being heated. Therefore, the ANE that flows away from the vehicle and the road, after a loss of containment, presents no risk of an explosion. The ANE in a tanker that has cooled down after surviving a vehicle fire without a loss of containment does not pose an explosion risk and may be pumped safely into a recovery tank.

Steel ANE tankers currently pose a risk of a pressure explosion as well as the subsequent risk of a detonation from ground-based ANE decomposing close to the tyre fire. More consideration and research needs to occur to facilitate an optimal emergency response for steel tankers.

# 11 Recommendations for safer road transport of ammonium nitrate explosion risk goods

## 11.1 Introduction

We will refer to 'AN explosion risk goods' as meaning the following products:

- AN suspensions or gels, grouped along with ANEs under UN 3375
- solid AN prill of UN 1942 and 2067
- hot, concentrated ammonium nitrate solutions (ANSOL), UN 2426.

This group of dangerous goods all contain AN, which in a fire scenario can decompose and potentially explode.

ANE is considered the safest of the AN explosion risk goods. The explosion risk of ANE is lower than that of AN and hot, concentrated AN solutions (ANSOL), because of the emulsion structure and the water content. The explosion risk from ANE only arises due to its AN content – first the emulsion needs to be destroyed and the water boiled off before the AN is capable of decomposition. The most common cause for initiation of AN explosion risk goods is from a fire event giving rise to the decomposition of AN. As a result, these recommendations should not be limited to ANE, but the transport of a broader category of AN explosion risk goods.

This chapter will discuss fire risk reduction measures for the safe transport of AN explosion risk goods.

The cost-effectiveness, application and implementation of the recommendations is required to be investigated by industry and Australian regulators in a cooperative effort.

It is intended that the recommendations will be formally communicated to relevant stakeholders including the national Competent Authorities Panel, Australian Standards, tanker manufacturers, industry safety groups and associations, and transporters.

## 11.2 Development of an industry-led code of practice for ammonium nitrate explosion risk goods

Recommendation 1

A national code of practice be developed by industry to provide detailed guidance on the safe road transport of AN explosion risk goods.

The mandatory ADG Code applies to the transport of dangerous goods, including all AN explosion risk goods throughout Australia, but does not provide sufficient detail to address this risk.

Among other things the ADG Code mandates the application of the series of standards AS 2809 that provide for the construction, design and maintenance requirements for dangerous goods road tankers. Parts 1 – General requirements for all road tank vehicles and 4 – Road tank vehicles for toxic, corrosive or ammonium nitrate emulsion, suspension or gel cargoes apply to tankers transporting UN 3375 substances such as ANEs.

Section 4.8.3 of AS 2809.4 recommends minimising the fire risk for UN 3375 tankers by:

- wheel bearing temperature monitoring
- tyre temperature and pressure monitoring
- fire suppression systems.

However, the standard contains no detail on the design or performance of these risk controls.

It is recommended that a code of practice be developed by industry to provide detailed guidance on the safe road transport of AN explosion risk goods.

A national code of practice needs to be a priority, considering the significant quantities of and large distances that AN explosion risk goods are transported throughout Australia and their importance to the resources sector. Among other things, the national code of practice should be based on the recommendations of this report.

## 11.3 Early detection of overheating

Recommendation 2

Vehicles transporting AN explosion risk goods should be fitted with a hub and tyre temperature and pressure monitoring system.

Early detection of high temperatures and fires is important to enable early intervention by the driver to extinguish the fire. Wheel hub temperature monitoring can detect high temperatures and allow early intervention to enable a fire to be combated. Tyre pressure monitoring may detect abnormal conditions that may indicate overheating is likely to occur.

Some transport companies have already taken the initiative of installing temperature and pressure monitoring systems to their vehicles, while others are using a manual hub temperature monitoring program when transporting AN explosion risk goods.

With a manual system, drivers measure the hub and tyre temperatures at periodic intervals during fatigue breaks and prior to entry to sites after travel. This system uses a hand-held heat gun and records the results. This has limitations as temperature measurements are done on a periodic basis and it is possible for a tyre fire to occur between measurements. Ideally, a constant monitoring system is needed that alerts the driver of overheating problems during travel.

## 11.4 Fire protection using mudguards

Recommendation 3

Mudguards with heat shielding properties (e.g. stainless steel) should be fitted, to protect the tank or cargo containing AN explosion risk goods from the heat radiation of a tyre fire.

A consideration must be given to minimising the amount of combustible materials used in the construction of the vehicle and trailer, rubber mudguards may not be the most suitable choice. They are likely to form part of a fire fuel load and reduce radiant heat protection to the tanker shell if they are consumed.

In the Great Central Road incident, the tanker trailer was fitted with rubber mudguards. Rubber mudguards may only deflect flames from a tyre fire away from the tank for a short period before igniting and contributing to the fire spread and severity.

The mudguards of vehicles transporting AN explosion risk goods should be made from heat shielding materials, for example stainless steel, rather than aluminium or plastic, as per AS 2809: part 1 section 2.9.4. This will provide flame deflection that will reduce the likelihood of flame contact with the tank wall and provide heat shielding.

An investigation of this incident has shown that it is likely to be beneficial to review the standard, to determine the most appropriate materials to be used, in order to improve the heat shielding properties.

## 11.5 Fire protection using fire screens

Recommendation 4

Consideration should be given to the practicality of fitting fire screens beneath loads of AN explosion risk goods.

Consideration should be given by industry to explore opportunities to incorporate a fire screen into the tanker vehicle design. This should include consideration of replacing aluminium trays with steel trays for loads of AN prill.

Steel fire screens (both vertical and horizontal) are already mandated for Category 3 quantities of explosives, such as ANFO, by section 6.4.2 of the Australian Code for the Transport of Explosives by Road and Rail (AEC3) and provide added protection from fire. Given the nature of the vehicles involved, this suggests the application of steel fire screens is achievable in certain circumstances.

Steel fire screens provide better fire protection for loads when compared to aluminium trays. In the Angellala Creek incident, the vehicle was fitted with an aluminium tray that melted and provided little protection to the AN (Department of Industry Resources and Mines (Qld), 2014). Six months after this incident a very similar incident occurred near a remote mine in WA, where the vehicle was fitted with a 6 mm checker steel plate tray. This incident did not lead to an explosion.

A similar steel firescreen design may be a practical option for loads of AN in intermediate bulk containers (IBCs). This arrangement would give IBCs a similar level of protection as AN transported in steel freight containers, or in large steel bulk containers.

It would also be beneficial for industry to investigate the feasibility of introducing steel fire screens to vehicles transporting ANE and ANSOL. The purpose of the firescreen is to shield the tanker from fire, as such it could follow the shape of the tanker or tank, rather than a horizontal design.

## 11.6 Shielding of brake and air supply lines

Recommendation 5

Critical components of the vehicle’s running equipment should be protected from rocks and debris for the safe operation of the vehicle.

From incidents reported to the Department and from the maintenance records obtained for this vehicle, it is known that vehicles travelling long distances on unsealed gravel roads are subjected to harsh conditions. The critical components of the vehicle’s running equipment, that is the wheels, brakes, axles and other parts of the vehicle and trailer located below the chassis, can fail due to impact by rocks and debris as well as abrasion through excessive vibrations.

It is recommended that these components be better protected from these hazards. Such equipment would include the booster springs for the brakes and the air supply lines for the braking system.

It may be possible to install shields in front of the booster brakes to afford them better protection and to run the air supply lines for the braking system in a more protected location such as on the inner side of the chassis. It may also be possible to engineer a solution to better protect the air supply lines (or sections of the air supply lines) such as what is done to protect the wiring systems on some vehicles, for example a strong conduit. Fitting of additional mudflaps may be another method of protecting the running gear.

A review into the use and effectiveness of air pressure detection systems should also be considered, to improve the driver’s ability to proactively respond to potential issues, such as air loss due to air supply line leaks.

Currently there appears to be a lag in time between where there is a loss of air in the air reservoir tank and when the air pressure light on a vehicle’s dashboard illuminates, meaning the driver is unaware that an issue is occurring and that the brakes are beginning to drag. Earlier alerts may prevent a tyre fire, particularly where the dust generated on gravel roads may prevent visible detection of a fire.

## 11.7 Vehicle firefighting capabilities

Recommendation 6

Vehicles should be fitted with a sufficiently large pressurised foam or water-based firefighting system that meets the requirements of Table 12.1 Note 4 of the ADG Code.

Recommendation 7

Automatic fire suppression systems should be considered for tyres of vehicles transporting AN explosion risk goods.

Recommendation 8

In order to support recommendation 6, it is recommended that the National Transport Commission (NTC) should conduct a review of Table 12.1 Note 4 of the ADG Code.

### 11.7.1 Appropriate foam or water-based firefighting system

In the Great Central Road incident, although the portable fire extinguishers complied with the regulatory requirements, the number and type fitted to the vehicle were inappropriate for the type and size of fire that was observed by the driver.

Water and/or foams are the most appropriate firefighting media for tyre fires. Dry chemical powder and carbon dioxide may not be as effective since burning tyres have enough heat energy to reignite after flame knockdown and require continuous cooling with water or aqueous foam. Fighting tyres with water requires significant quantities to cool the tyre and extinguish the fire. Foam or encapsulating agents have the added benefit of being a good blanketing agent that will adhere to the surface of a burning object and suppress the fire.

A foam firefighting system using compressed air or electric pumps may stand a higher chance of success than a portable fire extinguisher. The capacity of the firefighting system should be suitable to the load being carried and the size of the combination vehicle. This requires further analysis by industry to determine the appropriate volume required. Consideration should be given to where the system is located, the position of the hoses so they are readily accessible and that the hoses can reach all parts of the vehicle combination.

It is important to have both portable and fixed firefighting systems on combination vehicles that transport AN explosion risk goods. This gives the ability to fight different types of fires as well as the two systems combining to provide greater firefighting capacity. Consideration should also be given to the quantity of firefighting protection needed for when drivers are working alone or in remote areas.

### 11.7.2 Automatic fire suppression system

Automatic fire suppression systems for tyre fires are an emerging technology that are being trialled on some ANE tankers in Western Australia.

The advantage of these systems is that no input from the driver is required and there is an early detection of issues. The system will detect a tyre fire, alert the driver and flood the fire with water (with encapsulating agent) or foam.

It is recommended that industry investigate opportunities to incorporate automatic fire suppression systems on ANE tankers for the Australian environment.

### 11.7.3 Review of Table 12.1 within the ADG Code

It appears a change to the minimum requirement for firefighting equipment may be necessary. As a result of the findings of this investigation, the NTC should consider reviewing the appropriate types and sizes of portable firefighting devices and firefighting systems to be included in Table 12.1 Note 4 of the ADG Code.

## 11.8 Route planning

Recommendation 9

The driver should be provided with a Journey Management Plan (JMP) formulated after a risk assessment. Where possible, the transport of AN explosion risk goods should avoid the use of poorly maintained gravel roads.

It is recommended transport companies prepare, review and amend where necessary, an appropriate Journey Management Plan (JMP) incorporating route selection.

Most companies will already have a JMP in place for drivers to follow, often including a security plan (as required by the SSAN Regulations).

A risk assessment needs to identify hazards along the route drivers need to be aware of, including avoiding populated areas and environmentally sensitive locations. The risk assessment should be reviewed regularly. Prior to the journey, checks should be made for any recent environmental hazards such as flooding, fires and cyclones. Drivers need to drive to the conditions and the maximum speed for the road should be set in the JMP. This may be lower than the gazetted speed limit.

In the Great Central Road incident an alternative route for transport on a better road was not available, due to the remote location and limited transport routes.

Consideration should be given to which position an AN explosion risk goods carrying vehicle should be in a convoy. It may be beneficial to have another vehicle following behind the AN explosion risk goods vehicle, as this allows the vehicle behind to observe and alert if a fire or other issues occur.

## 11.9 Increased maintenance schedule of vehicles and trailers utilising unsealed roads

Recommendation 10

The maintenance schedule on vehicles should be intensified when driven on poorly maintained gravel or dirt roads.

The maintenance schedule of vehicles and trailers used for transporting AN explosion risk goods should be intensified for those regularly driving on unsealed roads.

The vehicle and trailers should be inspected regularly after long journeys on poorly maintained unsealed roads. For ongoing and regular routes, analysis of the maintenance required should inform the maintenance schedule for transport operators. Sections 6.3 and 8.0 detail the maintenance, faults and repairs performed on the vehicle involved in the Great Central Road incident in the six months prior to the incident. The trailers involved in the incident were dedicated for the transport to the Gruyere mine.

Particular attention should be given to parts of the vehicle critical to reducing the likelihood of a fire, such as the wheel bearings, braking systems, air supply line and temperature and pressure sensors.

## 11.10 Communications

Recommendation 11

Vehicles should carry an appropriate means of communication to be capable of raising the alarm at any point in the journey and to provide essential information to emergency services.

Maintaining communications on regional roads in remote Australia is challenging, with significant areas of the nation having no mobile phone coverage. Standard mobile phones and some GPS tracking systems may not be suitable for maintaining communications with drivers for purposes such as determining driver location for welfare or security tracking as they do not have coverage at all times. Satellite communication systems are a preferred method of monitoring as they have better coverage.

In the Great Central Road incident, the driver had no satellite phone and had no means of communicating with his employer or the emergency services to alert them of the incident. One of the other vehicles in the convoy had a satellite phone. The driver was able to contact that other vehicle via two-way radio and have them relay the alarm.

## 11.11 Emergency response planning

Recommendation 12

Emergency evacuation distances in the *Australian & New Zealand Emergency Response Guide Book*, Guide No. 140 should be increased to 1.6 km for fires involving ANE and ANSOL.

A double road train combination contains a load of approximately 61 tonnes of ANE, which is equivalent to approximately 50 tonnes of TNT.

It is recommended that an update be made to Emergency Guide No. 140 in the *Australian & New Zealand Emergency Response Guide Book*. The update should inform responders that the 1.6 km evacuation distance for AN vehicle fires should also apply to all UN 2426 and UN 3375 substances. 11.12 Training of drivers and fire fighters

### 11.12.1 Transport company responsibilities and driver training

Recommendation 13

Drivers must be appropriately trained and competent in the safe and secure transport of AN explosion risk goods.

Recommendation 14

Any party involved in a firefighting capacity of AN explosion risk goods should be aware of when it is safe to fight a vehicle fire transporting these products and when evacuation processes should be undertaken.

The consequences of any vehicle fire can be vastly different depending upon the early actions taken by the driver. Drivers need to know when it is safe to fight a vehicle fire involving AN explosion risk goods and when it is no longer safe. They also need to be able to distinguish between a 'vehicle fire' and a 'cargo fire'.

When a fire is in its infancy, and the driver has the correct firefighting equipment, it is possible to readily extinguish the fire without allowing it to escalate and become uncontrollable. When the fire does become uncontrollable and involves the product being transported, then it is necessary to evacuate and establish an exclusion zone.

This is critical if the incident was to occur in a built-up area where peoples lives are at risk or significant infrastructure could be damaged. Should the driver decide not to tackle the fire in its early stages, the consequential damage to the vehicle, surrounding environment and community can be greatly increased.

In the Great Central Road incident, the driver had correctly followed procedures by raising the alarm and attempting to extinguish the fire. He decoupled the tanker when the fire could not be extinguished and barricaded the road at a safe distance. Those actions were appropriate and timely.

Other incidents highlight that an early and appropriate intervention can prevent the fire causing significant damage to the vehicle or result in an explosion.

Drivers need to be sufficiently trained and rehearsed in the correct use of the on-board firefighting equipment and be prepared to use them where safe. It is important they know how portable extinguishers and firefighting systems on board their vehicles work and how to use them in an emergency. They also need to know its capabilities, limitations and the duration of the system operation.

A transport company requires a TERP (Transport Emergency Response Plan) when carrying these goods in bulk quantities. A driver must be familiar with the TERP, and all other company procedures that address an emergency response, such as communication systems and protocols in the event of an emergency. The driver must carry specific instructions in the cabin, as a requirement of the ADG Code. The instructions required are extracted from the *Australian & New Zealand Emergency Response Guide Book* (Guide No. 140).

As AN explosion risk goods are SSAN products, a Security Plan outlining the actions and procedures need to be taken in order to keep the product safe and secure is required.

Drivers need to be aware of this plan.

### 11.12.1 Firefighting response by other parties

All parties including emergency services (including volunteers and mine ERTs) involved in fighting a fire where AN explosion risk goods are involved, need to be aware of the product's characteristics in a fire and when it is no longer safe to fight a fire.

## 11.13 Large scale fire tests

Recommendation 15

Fire tests to be conducted to determine the rate of decomposition and explosive potential of ANE in open fires where the fuel and ANE entrapment are similar to the Great Central Road incident.

Recommendation 16:

Fire tests to be conducted on steel tankers to determine the effectiveness of the new emergency venting requirements of AS 2809.4 (2022).

### 11.13.1 Understanding decomposition of ground-based ammonium nitrate emulsion

There are benefits to industry to better understand how ANE performs in a ground-based fire, under similar conditions to the Great Central Road incident. It is important to know the rate of decomposition and the impact of the fuel from the burning of tyres and the duration of the fire.

For example, the question of whether the involvement of an additional tri-axle group of tyres was an essential factor for the Great Central Road explosion needs to be determined. Understanding the contribution of these factors is key to understanding how to minimise the likelihood of another ANE tanker explosion in future.

### 11.13.2 Emergency venting requirements

An understanding of the effectiveness of the emergency venting provisions required in the new edition of AS 2809.4 is essential to determine the potential for a pressure explosion within steel tankers.

The previous 2001 edition of AS 2809.4 had no specific design requirements for ANE tankers. The latest edition AS 2809.4 (2022) contains detailed ANE tanker design requirements including a large emergency vent, equivalent to one 500 mm diameter opening per 15,000 L tank capacity. These requirements will be mandatory from 1 April 2024 in Australia for the construction of all new ANE tankers, because of the mandating of edition 7.8 of the ADG Code on that date.

A large venting capacity is likely to significantly reduce the potential for a pressure explosion to occur in steel tankers. To resolve the questions of whether or when a pressure explosion occurs in a scenario where the tanker is engulfed, it would be desirable to conduct a large scale fire test with a steel tanker fitted out with the venting requirements of AS 2809.4 (2022).

# 12 Conclusions

The Great Central Road incident has raised a new awareness of ANEs potential to detonate after a loss of containment during a vehicle fire. The detonation arose from molten, sensitised, self-gassed AN, formed by the decomposition of ground-based ANE. The heat energy driving the decomposition was provided by the fuel from 26 tyres (the two tri-axle groups and two spare tyres) and approximately 2,400 kg of combustible liquid from the organic component of the ANE.

The exact mechanism of the explosion is not known, but potential shock initiation scenarios existed at the time which may have triggered the explosion.

Various factors likely increased the explosion risk. Most important was the entrapment of the ANE around the burning tyres, caused by the topography of the gravel road, which led to its decomposition. This entrapment is possible on most unsealed gravel roads of the type encountered in regional and remote Australia. Despite this explosion ANE remains the safest of the AN explosion risk goods.

ANEs have a high MBP, meaning that they cannot burn or explode at the atmospheric or tank pressures that could develop during a fire, while they remain in their original form (an emulsion). The ANEs structure protects it against chemical reactions and decomposition by an oily emulsion matrix of low thermal conductivity. The matrix encapsulates and protects the reactive AN component. The additional high water content further protects the emulsion from decomposition. The emulsion structure must be destroyed and the water must be boiled off before the temperature of the molten AN can climb above its decomposition temperature to produce explosion sensitive, self-gassed, molten AN and this process takes time.

All plausible pathways to an explosion from an ANE tanker start with a vehicle fire and all reasonably practicable precautions need to be taken to prevent a fire.

If fires are detected early and there is sufficient fire fighting capability to extinguish the fire then the likelihood of an explosion is negligible.

The recommendations in Chapter 11 should be consulted for all the various risk minimisation measures.

Change is needed to ensure the ongoing safe transport of ANE. Further discussion with industry and regulators is required to examine the recommendations and set priorities.

It is the Department’s view that a good starting point would be the development of a national code of practice by industry for *The safe road transport of AN explosion risk goods*. An effective code would consider all the recommendations and formulate them using the technical expertise that exists in industry.

Further research is needed to gain a better understanding of the explosion risk of ANE where there has been a loss of containment. A better understanding of the rate of decomposition of ground-based ANE is necessary to answer questions including whether the involvement of the second tri-axle group of tyres was an essential element in the explosion. Large-scale fire tests of ground-based ANE under similar fuel loading and ANE spread, as experienced during the Great Central Road incident, will lead to a better understanding of the decomposition and inform emergency response procedures.

In addition large-scale fire tests of ANE steel tankers fitted with the improved venting requirements of AS 2809.4 (2022) would determine whether steel ANE tankers can avoid a pressure explosion and are a safer method to transport ANE when compared to aluminium tankers.

Further large scale fire tests under a variety of weather conditions for both aluminium and steel tankers could better inform the effect that weather conditions have on the development of a fire and potential to lead to an explosion.

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# Appendix 1 The explosion risk of ammonium nitrate emulsions in an open fire

## 1.1 Introduction

An explosion of ANE in an open fire has previously not been reported. An understanding of the decomposition of ANE is gained by studying the literature on the modified vented pipe test (MVPT). However, the modified vented pipe is a steel vessel with a restricted opening in the top and ANE in an open fire will behave differently in several aspects that will be discussed here.

This appendix focuses on the relevant literature to predict the likely outcome of pouring large quantities of ANE onto an intense, prolonged tyre fire involving loss of containment from a road tanker. It is important to consider this within the context of Appendix 2, which details the outcome of tyre fires in the Scandinavian full-scale fire tests and Chapter 7 regarding the outcome of other ANE tanker/tank incidents involving fire.

Until the recent Great Central Road incident, ANEs in Australia have been manufactured, transported, stored and used in large quantities since the 1980s without incident of explosion during transport or any other activity.

The explosion-insensitivity of ANEs is mainly due to their high water content, typically ranging from 14%-25% as well as the sequestering of the AN, which is the reactive component, within a hydrophobic oily matrix.

Past experience has shown that combustion and decomposition of ANEs resulting from direct and indirect flame impingement without confinement at atmospheric pressure, is limited to the surface area impinged by the flame. This ceases as soon as the external flame is removed. ANEs do not support combustion or detonation while in their original form.

Hsu (2016) provides a good introduction to the Minimum Burning Pressure Test (MBPT) introduced and developed by the Canadian Explosives Research Laboratories (CERL) and explains that CERL have demonstrated that ANEs cannot burn, deflagrate or detonate while in their original emulsion form without very high pressures, at over 56 bar.

After being subjected to heating for extended periods, the ANEs emulsion structure breaks down and it is no longer in its original form. The resulting AN/fuel mixture becomes vulnerable to combustion and, after the water content has boiled off, to deflagration. Prior to the Great Central Road incident, the evidence from the Scandinavian full-scale fire tests with the limited volumes of ANE used demonstrated that flame impingement on ANEs in unconfined, open fires would not result in an explosion.

Such different conditions have now occurred. The Great Central Road incident involved much larger quantities of ANE and different circumstances to the Scandinavian full-scale fire tests as fully explained in Chapter 9 and Appendix 2.

For an explosion to occur, fire exposure of ANE released to the ground would require the entrapment of the ANE underneath the tanker, or at least close to the tanker's burning tyres. This would transmit sufficient heat to destroy the emulsion structure and boil off the water and decompose the AN.

Weather conditions for the Great Central Road were much warmer and dryer compared to the Swedish conditions. From a review of the literature, similar conditions have not been experienced before in an experimental or accidental ANE aluminium tanker fire.

The behaviour of ANE in a large and prolonged fire with direct flame impingement into the ANE is poorly understood and likely to be complex and require further research.

## 1.2 The behaviour of ammonium nitrate emulsion in the MVPT and in an open fire

Kennedy (2003) has undertaken significant research to understand the behaviour of ANEs in the MVPT.

It is important to understand that the steel modified vented pipe vessel represents a confined space with a restricted opening and lacks the direct flame impingements of an open fire. Any comparison with the unconfined decomposition of ANE in an open fire needs to be made with caution. Open fire behaviour of ANE is more complex because the mixture is at different temperatures and therefore at different stages of decomposition, unlike in the modified vented pipe vessel where temperatures in the decomposing mixture are relatively evenly distributed.

Most significantly, the role that the fuel component of the ANE adopts in an open fire will be different to that in the MVPT. The fuel component will combust and combine with oxygen in an open fire. In contrast it will be consumed in the final phase of the MVPT in an explosive deflagration reaction, which is the same explosive reaction that occurs when ANFO explodes.

Once the temperature of the ANE in the modified vented pipe vessel reaches the boiling point of the AN solution (approximately 140 °C), the emulsion is destroyed and replaced by a broken unstructured suspension of small oil droplets dispersed in the aqueous phase. This allows the presence of convection currents and the efficient distribution of heat from hot to cold areas.

Continued heating of the bottom of the modified vented pipe vessel with the gas burner progressively boils off water and the aqueous AN solution becomes more concentrated. When the temperature reaches 168 °C, the AN solution is now 95% concentrated with insufficient water left to support any turbulence from boiling water.

At this stage of the decomposition the mixture of a hydrocarbon and an emulsifier, separates out and floats to the top due to its low density of approximately 0.88 g/cc, forming an oily phase. The AN solution now at 97% AN concentration, is reported to have a density of approximately 1.43 g/cc and a boiling point of approximately 183 °C (Shah & Roberts, 2018).

Above 210 °C the molten AN will start to slowly decompose. At about 230 °C there is rapid decomposition of the AN, resulting in nitrous oxide and water (steam) causing turbulence of the two phases. Water vapour emission from the molten AN will then be completely replaced by the gaseous decomposition products from the AN, which are nitrous oxide and water:

$$NH_4NO_3 \rightarrow N_2O + 2H_20 \quad \Delta H = -0.73 \text{ MJ/kg} \quad \text{(Reaction 1)}$$

The resulting AN/organic mixture self-gasses, making it more sensitive. At approximately 250 °C there is some overflow from the modified vented pipe vessel due to the lower density and larger volume of the mixture. The overflow momentarily intensifies the fire from the gas burner.

Above 280 °C the increased turbulence caused by the gas production and the increasing temperatures initiates the explosive reaction of the oily phase with the molten AN. This results in a violent thermal run-away reaction with ignition in the headspace of the vessel at above 280 °C. Violent venting occurs as the deflagration front is thought to travel from the top of the mixture to the bottom. The main deflagration/explosion reaction is:

$$NH_4NO_3 + \text{“}CH_2\text{”} \rightarrow N_2 + H_20 + CO_2 \quad \Delta H = -\ 3.80\ \text{MJ/kg} \quad \text{(Reaction 2)}$$

The organic component is consumed in this potentially explosive reaction, which is the most exothermic of all the various AN decomposition reactions. The same reaction applies to exploding ANFO. The “$CH_2$” denotes the organic carbon mixture with an approximate carbon to hydrogen ratio close to 1 to 2.

By contrast, a vehicle fire involved in a loss of containment, subjects the ANE to direct flame contact, hence the fate of the organic fuel component will be different from that in the MVPT.

In an open fire, there will be large temperature variations of the ANE mixture depending on its proximity to the fire.

The combustible liquid will combine with oxygen and will burn off and increase the temperature of the mixture. This will occur as the mineral oil has an initial flashpoint of less than 100 °C.

The most likely scenario is that the tanker trailer fire at Great Central Road started with ANE in a fire and finished up with molten AN in a fire as the water was driven off and the hydrocarbons consumed by the fire.

With all or most of the fuel having burned away, any explosion will involve Reaction 3 rather than the ANFO explosion of Reaction 2:

$$2NH_4NO_3 \rightarrow 2N_2 + 4H_20 + O_2 \quad \Delta H = -\ 1.47\ \text{MJ/kg} \quad \text{(Reaction 3)}$$

Reaction 3 has approximately 39% of the explosive power of Reaction 2 occurring in the MVPT. It has a much lower efficiency with only a fraction of the available AN participating in the explosion.

## 1.3 The formation of white fumes during ammonium nitrate decomposition

The formation of white fumes is characteristic of the decomposition of pure, molten AN and has been studied by Kennedy under the same conditions as the MVPT test.

Pure AN, in contrast to ANE, behaves without a deflagration in the MVPT because there is no organic component.

Once the pure molten AN reaches about 290 °C, the exothermic Reaction 1 and the endothermic Reaction 4 are able to stabilize the decomposition at approximately 292 °C and the vessel contents are observed to fume off with thick white “smoke” over a period of about 11 minutes.

$NH_4NO_3 \Leftrightarrow NH_3 + HN0_3 \quad \Delta H = +\ 2.00\ MJ/kg$ (Reaction 4)

Unconfined, at atmospheric pressure Reaction 1 and 4 are capable of consuming all of the molten AN under continual heating. Any explosion after prolonged decomposition would involve a much reduced mass of molten AN.

Reaction 4, unlike the exothermic reactions, is reversible and depends on the vapour pressure above the molten AN – the forward reaction stops in conditions of confinement that do not allow ready escape of decomposition gases. Under those circumstances the temperature quickly rises in a thermal runaway reaction that can lead to deflagration and detonation.

The white fumes arise from a combination of condensing nitric acid and the reversal of reaction 4 in the cooling gas phase producing subliming super-fine particles of crystalline AN.

The white 'smoke' seen by witnesses at the Great Central Road incident was most likely subliming AN.

# Appendix 2 Scandinavian full-scale fire tests and comparison with the Great Central Road incident

## 2.1 The Scandinavian full-scale fire tests using aluminium tanks

Scandinavian governments and industry conducted three full-scale fire tests on 5 mm thick aluminium tanks:

1. Halkavarre in Norway (1996) – the volume of ANE was 3,000 L in an uninsulated tank
2. Kuosanen in Sweden (2002) – 6,000 kg of ANE was used in an uninsulated tank
3. Kuosanen in Sweden (2007) – 6,000 kg of ANE was used in an insulated tank (apart from the 75 mm rock wool insulation this experiment was identical to the one in 2002).

The Kuosanen experiments (2002 and 2007) used aluminium tanks mounted on a two-axle chassis with a total of 8 tyres on their wheels and 400 L diesel. The tank trailer and diesel fuel were placed in a steel basin. The tank had two compartments, but only one compartment of 5,000 L (containing 6,000 kg) was used.

The tanks were equipped with instruments to measure temperature (internally and externally) and pressure.

### 2.1.1 The results of these experiments

The performance of the aluminium tanks were consistent in all three experiments.

The testing found that the aluminium tank splits open on the application of external heat with peak external temperatures of 890 °C (2002 test) and 1,120 °C (2007 test) allowing ANE to spill out through holes and cracks and pour into the fire. The spilled ANE intensified the fire without deflagration, and ceased burning when the external fuel was exhausted.

There was a significant loss of containment of ANE (75%) in the 2002 test through large holes within the side of the tank after 6 minutes and 40 seconds from ignition. The 2007 test had significantly smaller holes due to the insulation (the tank was insulated with rock wool) inhibiting the heating of the tank and allowed 50% of the ANE to escape through an elevated small hole after 10 minutes from ignition.

The outcomes of the fire tests led the Scandinavian government to favour aluminium ANE tankers, and other non-confining materials, over steel tankers, which are likely to suffer a pressure explosion under fire conditions.

During the 2002 experiment, it is also of note that two tyre pressure explosions occurred after 5 minutes 20 seconds and after 5 minutes 50 seconds from the time of ignition of the fire.

## 2.2 Conditions that make the Great Central Road incident different from the Kuosanen experiments

This section summarises the information from Chapter 9 and contrasts the Great Central Road conditions with the corresponding conditions in the Kuosanen experiments and explains why the Kuosanen experiment did not lead to an explosion (Figure Appendix 2.1).

Of most significance are the conditions in the Great Central Road incident that led to an increased heat output of the external fire over a longer period than Kuosanen. This resulted in an increased rate of decomposition of the ANE once on the ground. While the two Kuosanen experiments used the same aluminium tank and set ups, the Kuosanen experiment of 2002 is more relevant since it used an uninsulated aluminium tank and this resulted in the larger loss of containment of ANE of 75%.

The most significant differences of the Kuosanen 2002 experiments compared to the Great Central Road incident are listed below.

- The experiments were conducted in the snow and the weather conditions were significantly different when compared to the Great Central Road incident. Temperatures were around 0 °C compared with 32 °C at the Great Central Road incident. The winds at Kuosanen were cold and strong compared to the Great Central Road incident. The wind significantly decreased the heating on one side of the tanker. There was a difference in temperature measured of 600 °C. The cold temperatures and the higher wind speed significantly reduced the heat transfer from the fire to the tank and importantly from the fire to the escaping ANE on the ground. Further detail on the weather conditions experienced at Great Central Road are found in Figure Appendix 2.1 and Appendix 6.
- The amount of external fuel, including from tyres, available for the fires was substantially smaller in the Kuosanen experiments when compared to the Great Central Road incident. The Great Central Road incident involved 26 tyres compared to 8 in each of the Kuosanen experiments.
- There was a loss of containment of 75% of the ANE (4,500 kg) at the Kuosanen 2002 experiments. In the Great Central Road incident there was a loss of containment of up to 33,850 kg (100% of the load).
- The corresponding amounts of organic component to fuel the fire were approximately 315 kg in Kuosanen compared to approximately 2,400 kg for the Great Central Road incident. The larger heat of combustion from the fuel in the ANE in the Great Central Road incident is significant.

| Relevant condition | Kuosanen 2002 | Great Central Road Incident |
|---|---|---|
| Ambient temperature (°C) | 0 | 31.8 |
| Wind speeds (km/hr) | 7.2-14.4 | 3.4 |
| Relative humidity | 74.5% | 17% |
| Time before tyre/diesel stopped burning (mins) | No information, but 54 for Kuosanen 2007 | 120 |
| External fuel involved | 8 tyres and 400 L diesel fuel | 26 tyres, no diesel from fuel tanks |
| Estimated quantity of ANE released from tanker (kg) | 4,500 | 33,850 |
| Amount of organic component (kg) | 315 | Approximately 2,400 |
| Amount of AN content in spilled ANE (kg) | 4,380 | Approximately 25,500 |
| Initial ground clearance to the bottom of the aluminium shell (mm) | 1,000 | 800 |
| Final ground clearance to the bottom of the aluminium shell (mm) | Not known | 450 |

*Figure A2.1 Comparison of conditions at Kuosanen and Great Central Road incident*

# Appendix 3 Explanation of the size of the explosion

It is estimated that the size of the explosion was between 1-3 tonnes of TNT equivalent, and was an explosion of sensitised AN rather than ANE. This estimate is based on the effects of the blast overpressure and the size of the crater.

The likely contributing factors that resulted in the explosion being smaller than expected in this incident are as follows:

- A large part of the AN content of the emulsion would have decomposed during the 90 minutes (when loss containment occurred) before the explosion occurred, as a result of the fire.
- The explosive energy of AN is just under one third of the explosive energy of TNT.
- AN explosions of this type, involving heating of AN that is contaminated with fuel and/or incompatible substances, are very inefficient. Less than half of the available AN is likely to participate in the explosion. The majority remains unconsumed and is distributed by the explosion over a very wide area around the crater site. Note, no AN was observed at the Great Central Road incident scene.
- It is expected that prior to the explosion that there was intact ANE and unsensitised AN at the outer margin of the ANE pool, spread too far from the heat sources to be affected. The products (ANE/AN) on the margins of the pool will not participate in the explosion. The amount of products are likely to be small in quantity because most ANE/AN was trapped close to the burning tyres and under the tanker.
- There will also be sensitised AN in areas spread too thinly on the ground to have the critical diameter to participate in the explosion. In this case much of the ANE was spread over a large area of 120 m².

*The SAFEX Good Practice Guide: Safe Storage of TGAN* published in 2014 as revision 2 recommends an overall TNT equivalence in the range of 3-16% for AN involved in a detonation assuming an initiation mechanism involving the heating contaminated molten AN. The actual overall TNT equivalence in that range is unknown and depends on the extent of contamination – see Figure A3.1. An estimate of 1.5 tonnes TNT equivalent has been used to calculate the maximum amount of AN available from the ANE within the tanker trailer at Great Central Road.

| Property | Detonation from heating a contaminated melt of AN |
|---|---|
| Chemical TNT equivalence | 0.32 |
| The efficiency of explosion depends on the extent of contamination and the spread of the AN | 10-50% |
| OE is the Overall TNT equivalence | 3-16% |
| Estimated mass of TNT – Q to give the observed damage to snap branches at 120 m | 1.5 tonnes |
| Equivalent mass of AN consumed in the explosion to give the energy corresponding to Q.<br>(It assumes 100% efficiency, but the expected efficiency is 10 to 50%). | AN = Q/0.32 = 4.7 tonnes |
| Maximum available AN in the maximum available ANE of 33.85 tonnes. | Approximately 25 tonnes |

*Figure A3.1 Properties of an AN explosion from contaminated molten AN (estimate of 1.5 tonne TNT equivalent) (SAFEX guide)*

The overall TNT equivalence (OE) is the product of the chemical TNT equivalence of 0.32 and the efficiency of the explosion:

OE = 0.32 x Efficiency of the explosion

In an explosion with an OE of 16%, only 50% of the AN is consumed in the explosion and 50% remains unreacted.

Figure A3.1 provides the mass of available ammonium nitrate (AAN) that is potentially available to explode and the corresponding OE using the relationship:

AAN = Q/OE where Q = 1.5 tonnes.

The maximum overall TNT equivalent OE is set by the SAFEX Guide to be 16% and the minimum is set as 3%. However, in this particular case, the minimum overall TNT equivalence is approximately 6%, because the maximum possible AAN is approximately 25 tonnes, as explained in Figure Appendix 3.1.

The most likely overall TNT equivalence is likely to be somewhere between 11% and 16%, because the larger portion of the original AN would have decomposed during the 90 minutes (see section 9.4) the ANE was involved in the fire.

An overall TNT equivalence OE of 11% assumes that 13.6 tonnes of AAN is available to explode, because 11.4 tonnes of AN has already decomposed at the time of the explosion (25 tonnes minus 13.6 tonnes = 11.4 tonnes). It also assumes that 4.7 tonnes of AN has exploded and 8.9 tonnes has remained unreacted, remaining somewhere in the environment, as noted in Figure A3.2.

An overall TNT equivalence OE of 16% assumes that 9.4 tonnes of AAN is available to explode, because 15.6 tonnes of AN has already decomposed at the time of the explosion (25 tonnes minus 9.4 tonnes = 15.6 tonnes). It also assumes that 4.7 tonnes of AN has exploded and 4.7 tonnes has remained unreacted, remaining somewhere in the environment after the explosion as noted in Figure A3.2.

| Overall TNT equivalence (OE) | AN that has already decomposed before the explosion in tonnes | Mass of AAN available to explode in tonnes | Mass of AN consumed in the explosion in tonnes | Mass of AN remaining after the explosion in the environment tonnes |
|---|---|---|---|---|
| 6% (Minimum) | 0 | 25.0 | 4.7 | 20.3 |
| 11% | 11.4 | 13.6 | 4.7 | 8.9 |
| 16% (Maximum) | 15.6 | 9.4 | 4.7 | 4.7 |

*Figure A3.2 Mass of AN available for the explosion after decomposition (AAN) and corresponding overall TNT equivalence (OE)*

# Appendix 4 Ammonium nitrate emulsion

## 4.1 What are ammonium nitrate emulsions?

An emulsion consists of microscopic droplets of a super-saturated aqueous solution of the nitrate oxidiser. These are evenly dispersed within a very thin matrix of liquid hydrocarbon and organic emulsifier, forming a continuous phase. The droplets typically have a diameter of the order of 5-15 micron. The structure of the two phases is stabilised by a proprietary emulsifier.

An emulsion achieves the most intimate contact possible between a liquid oxidiser and a liquid fuel, resulting after sensitisation and booster initiation, in a very rapid chemical reaction and higher velocities of detonation than other AN/fuel mixtures such as AN suspensions or ANFO. ANEs are resistant to moisture unlike ANFO because its continuous organic phase repels water.

## 4.2 Further information regarding the ammonium nitrate emulsion involved in the incident

The ANE involved in the Great Central Road incident is an authorised formulation (since July 2019). The ANE contains AN without another nitrate (single salt), it is uninhibited and unsensitised. It is manufactured specifically for use as precursor for bulk blasting explosives in the mining industry. The product is a standard ANE consistent with other ANEs on the market. The product has a mineral oil with an initial flashpoint of less than 100 °C.

It has a water content in the middle range of 14-25%, resulting in a high minimum burning pressure (MBP) (Singh et.al,, 2016). ANEs cannot burn or deflagrate until the MBP is exceeded. The MBP of the formulation in the Great Central Road incident can be estimated to be approximately 100 bar and is well above the required 56 bar threshold set by CERL (Hsu, 2016) and the UN Manual of Tests and Criteria. ANEs are regarded as explosive, rather than non-explosive, if the MBP is below 56 bar.

The explosive derived from the ANE has been authorised by the Chief Dangerous Goods Officer of Western Australia under the *Dangerous Goods Safety Act 2004*. This authorisation required among other things the submission of the test results of the UN Test Series 8 for the unsensitised ANE. Negative test results are required to determine the product is not a Class 1 (explosive) and it permits the transport of the ANE under a non-explosive classification of UN 3375, Division 5.1 – “ammonium nitrate emulsion or suspension or gel, intermediate for blasting explosives”. The ANE passed the following tests outlined in the UN Manual of Tests and Criteria:

- Type 8 (a): a test to determine the thermal stability
- Type 8 (b): a test to determine sensitivity to intense shock
- Type 8 (c): a test to determine the effect of heating under confinement
- Type 8 (d): a method to evaluate the suitability of transport in portable tanks.

Type 8 (d) refers to both the vented pipe test Type 8 (d) (i) and the modified vented pipe test Type 8 (d) (ii) and are required for the transport in portable tanks, rather than for the purpose of classification as UN 3375. In this case the MVPT was conducted with complete consumption of all ANE – the test vessel was not ruptured or deformed, providing a typical negative result. The formulation that was tested was within the tolerances of the formulation of the batch of ANE involved in the explosion. This test was performed on the product in 2019 and more recently in February 2023 with identical results.

## 4.3 Physical and chemical analysis

A sample of ANE, from the same day of manufacture as loaded into the tanker, was retained by the manufacturer for physical and chemical tests under direction by the Department. The sample was stored in a secure and climate controlled area.

A sample of ANE was also collected from the lead tanker (that arrived safely to the mine site on 24 October 2022). At the mine site and three days after the incident, the Department undertook a density check of the product and found it to be 1.33 g/cc, which was consistent with the density when it left the manufacturer's site. A sample of ANE, taken from the lead tanker trailer, was then transported by road securely back to Perth, where it was stored in a secure location before physical and chemical tests could be performed.

Analysis results of the two samples (from the lead tanker and the sample retained by the manufacturer) were consistent and within the manufacturer's tolerances for this formulation, chemical analysis, physical property tests such as viscosity, density and droplet size.

In addition to the test performed on the ANE samples, the Department also reviewed quality assurance records for the manufactured product and discussed standard operating procedures with the manufacturer. No issues were identified.

*Figure A4.1 Density measurement of ANE from the tanker trailer that arrived at Gruyere mine site*

## 4.4 Conclusions

The investigation could not identify any inconsistencies between the manufactured formulation and physical and chemical properties of the product that was involved in the Great Central Road incident.

No sensitising chemicals were being transported on this vehicle, which could have reacted with the emulsion during the fire.

# Appendix 5 Detailed timeline of events

| Date and time | Details |
|---|---|
| **Sunday 23 October 2022** | |
| 09:26 am | Vehicle arrives at CSBP for loading. |
| 1:28 pm | Loaded vehicle departs CSBP for Gruyere mine site. |
| Night | Driver sleeps overnight on the outskirts of Leonora. |
| **Monday 24 October 2022** | |
| 5:30 am | Driver re-commences journey to Gruyere mine site. |
| 7:00 am | Driver arrives in Laverton and commences driving on the Great Central Road |
| Approximately 9:00 am | Driver joins two other vehicles on the road near Pines Rest and drives in convoy with other trucks. As there is no break, there is no opportunity to know whether damage had already occurred at this point.<br>The ANE tanker trailer is the last vehicle in the convoy. |
| 9:31 am | Driver notices smoke from rear tyres on the passenger (left-hand) side of the rear tanker and pulls over. |
| 9:31 am | Driver alerts the other 2 drivers of possible fire on his two-way radio. |
| 9:33 am | Driver uses a fire extinguisher to try and extinguish fire. |
| 9:41 am | Emergency services and transport company contacted by a driver in one of the vehicles in the convoy. |
| 9:45 am | Driver has now used all extinguishers, but the fire persists. He starts to disconnect the rear tanker trailer from road train and notices the fire had progressed to the tyres on the driver side.<br>Department of Fire and Emergency Services (DFES) contacted about incident. DFES begin liaising with volunteer fire services about resources to assist with exclusion zones. |
| 9:50 am | Driver leaves the scene and evacuates to Mount Shenton – Yamarna Road.<br>He notices that the flames are 600-900 mm high and approximately 450 mm higher than the rear mudguard. The driver notices black smoke from the fire and that the two air bags had burst. |
| 9:55 am | Driver arrives at Mt Shenton intersection to set up a road block at the turn-off to the mine site, approximately 3 km east of the incident side. |
| 9:59 am | Gruyere ERT become aware of incident. |
| 10:05 am | Driver notices for the first time white smoke among the black smoke from the incident fire. |
| 10:25 am | Gruyere ERT mobilise and depart mine site.<br>DFES begin contacting responders regarding establishing a 2 km exclusion zone either side of the burning tanker and dolly. |

| Date and time | Details |
|---|---|
| 10:40 am | Roadblock established within Laverton by Local Government Authority (LGA). |
| 10:50 am | Gruyere ERT arrive at the Mt Shenton exclusion zone/barricade. |
| 10:50 am | DFES contacted by Gruyere ERT. The dolly and trailer appear to be fully involved in the fire.<br>ERT advised that they should enter the exclusion zone to remove traffic located between the burning trailer/dolly and eastern barricade, using beacons and loud speaker.<br>Exclusion zone from the western side (east of Laverton) not yet established. |
| Approximately 11:05 am | ERT fire tender enters exclusion zone to approximately 1,300 m east of the burning tanker to warn and to usher a motor cycle and vehicle out of the exclusion zone. |
| Approximately 11:05-11:10 am | ERT member on the fire tender inside the exclusion zone has a clear line of sight of the trailer fire, having a front-on view and confirms the dolly wheels are on fire.<br>He sees fire on the ground, beneath the tyres.<br>He sees smoke changing colour from dark to grey to really white smoke in a plume about 20 m high. |
| 11:15 am | Driver told he can leave and deliver ANE in leading tanker now that ERT are on site. |
| 11:33 am | ANE tanker explodes. A fire ball and a plume of smoke approximately 1 km high is observed by the ERT and WA Police.<br>GeoScience Australia recorded the explosion occurred at 11:33:00.4 Australian Western Standard Time.<br>Spot fires break out in the bush surrounding the explosion from hot shrapnel. |
| 1:30-3:00 pm | Mine Survey team arrive and fly drone over incident scene.<br>DFES fly propeller plane over incident scene, collect images and monitor spot fires.<br>Spot fires are still burning. |
| 4:10 pm | DFES arrive on site and mine ERT are stood down. |
| **Tuesday 25 October 2022** | |
| Early afternoon | Road re-opened to public after LGA have the mine fill in the crater. |
| **Wednesday 26 October 2022** | |
| Noon | The Department's investigation team arrive at incident scene and commence investigation. |

*Figure A5.1 Detailed timeline of incident*

*Note: All times are represented in Australian Western Standard Time (UTC + 8) and some are approximated.*

# Appendix 6 Weather observations

Weather data was obtained from the Gruyere mine site weather station, located approximately 40 km from the Great Central Road incident.

The conditions on the day were fine, warm weather of approximately 32 °C, low relative humidity of 17% and air pressure 1,002.7 hPa.

The wind was light and generally in a westerly wind direction averaging west-south-west.

The tanker trailer combination stopped on the side of the road, which ran from west to east, so the initial wind direction provided favourable conditions for the potential spread of fire from the rear to the front tri-axle group.

Figure Appendix 6.1 provides the relevant weather information from observations at the Gruyere mine site. It should be noted that over such a distance, wind speed and direction vary.

| 24 October 2022 Time (AWST) | Temperature °C | Wind direction | Wind speed km/h | Wind gust in km/h |
|---|---|---|---|---|
| 9:30 am | 33.6 | West-north-west | 2.4 | 5.8 |
| 10:00 am | 33 | West | 4.9 | 7.9 |
| 10:30 am | 31.8 | West-south-west | 4.4 | 7.5 |
| 11:00 am | 30.6 | West-south-west | 2.3 | 4.1 |
| 11:30 am | 29.8 | South-west | 2.8 | 4.5 |
| Averaged | 31.8 | West-south-west | 3.4 | 6.0 |

*Figure A6.1 Weather data table from Gruyere mine site weather station during the tanker fire*

The ambient weather conditions were also conducive in minimising heat losses to the environment. Comparisons of the relative conditions of Great Central Road and Kuosanen fire tests are discussed in Appendix 2.

# Appendix 7 Abbreviations and units

| | |
|---|---|
| ADG | Australian Dangerous Goods |
| ADG Code | Australian Code for the Transport of Dangerous Goods by Road & Rail Edition 7.8 |
| AEC2 | Australian Code for the Transport of Explosives by Road and Rail (2nd Edition) |
| AEC3 | Australian Code for the Transport of Explosives by Road and Rail (3rd Edition) |
| AN | Ammonium nitrate |
| ANE | Ammonium nitrate emulsion |
| ANFO | Ammonium nitrate fuel oil mixture |
| AN explosion risk goods | AN suspensions or gels, grouped along with ANEs under UN 3375; solid AN prill of UN 1942 and 2067; and hot, concentrated ammonium nitrate solutions, UN 2426 |
| ANSOL | Ammonium nitrate solutions |
| AS 2809 | Australian Standard AS 2809 *Road tank vehicles for dangerous goods* |
| AS 2809.1 | Australian Standard AS 2809.1:2020 *Road tank vehicles for dangerous goods, Part 1: General requirements for all road tank vehicles*<br>Australian Standard AS 2809.1:2023 *Road tank vehicles for dangerous goods, Part 1: General requirements for all road tank vehicles* |
| AS 2809.4 | Australian Standard AS 2809.4:2022 *Road tank vehicles for dangerous goods, Part 4: Road tank vehicles for toxic, corrosive or ammonium nitrate emulsion, suspension or gel cargoes* |
| DCP | Dry chemical powder |
| DFES | Department of Fire and Emergency Services |
| DGSC | Dangerous goods security card |
| DG Transport Regulations | WA Dangerous Goods Safety (Road and Rail Transport of Non-explosives) Regulations 2007 |
| ERT | Emergency response team |
| GCR | Great Central Road |
| IBC | Intermediate bulk container (defined in ADG Code) |
| JMP | Journey Management Plan |
| LHS | Left hand side |
| MBP | Minimum Burning Pressure |

| | |
|---|---|
| MBPT | Minimum Burning Pressure Test |
| MPU | Mobile Processing Unit |
| MVPT | Modified Vented Pipe Test |
| NEQ | Net explosive quantity |
| NTC | National Transport Commission |
| OEM | Original Equipment Manufacturer |
| PPE | Personal protective equipment |
| RHS | Right hand side |
| SSAN | Security sensitive ammonium nitrate |
| SSAN Regulations | Dangerous Goods Safety (Security Sensitive Ammonium Nitrate) Regulations 2007 |
| TERP | Transport Emergency Response Plan |
| The Department | Department of Mines, Industry Regulation and Safety |
| UN Manual of Tests and Criteria | United Nations Manual of Tests and Criteria, Seventh revised edition 2019 |
| VOD | Velocity of Detonation |
| WA Police | Western Australian Police Force |

## Units

| | |
|---|---|
| Bar | Metric unit of pressure equal to 100 kPa |
| g/cc | grams per cubic centimetres |
| kL | kilo Litres |
| kPa | Kilo Pascals |
| L | Litres |
| m/s | metres per second |
| $m^2$ | metres squared |
| psi | pounds per square inch |

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